NON-NUMERICAL APPLICATIONS OF COMPUTER PROGRAMMING IN THE CONSTRUCTION OF PROBLEM ORIENTED LANGUAGES

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THESIS

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by

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A discussion of several non-numerical techniques that are useful in FORTRAN programming is presented. The use of these techniques is then illustrated with a problem oriented language called CAL-NPS. This last program is a derivation of a code named CAL written by Professor E. L. Wilson of the University of California, Berkeley, California.

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Non-Numerical Applications of Computer Programming in the Construction of Problem Oriented Languages

by

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ABSTRACT

A discussion of several non-numerical techniques that are useful in FORTRAN programming is presented. The use of these techniques is then illustrated with a problem oriented language called CAL-NPS. This last program is a derivation of a code named CAL written by Professor E. L. Wilson of the University of California, Berkeley, California.

TABLE OF CONTENTS

I. INTRODUCTION

In writing Problem Oriented Computer Languages several non numerical applications of computer programming must be mastered and the literature about such activities is nearly nil for the FORTRAN language. It is to these problems that this work addresses itself. The professional programmer would probably elect to write these codes in machine language but the user who only knows FORTRAN cannot afford time to learn the various machine languages in use today. All of the features discussed below are programmable in FORTRAN and illustrations are given in each use.

The CAL language is then used to illustrate how these features are incorporated in a problem oriented language. The CAL program was developed by Professor Edward L. Wilson of the University of California, Berkeley, California, for Structural Mechanics and Structural Engineering.

CAL combines matrix manipulation routines with direct stiffness computation options to produce a program for the automated analysis of structures. CAL also has significant capabilities as an instructional tool in linear algebra.

In order to use any structural analysis program it is necessary to idealize the structure into a series of joints connected by structural members. The joints are commonly referred to as nodal points and the structural members as elements. The program input consists of:

a) nodal point locations;

b) information on how nodes are connected;

c) boundary conditions that are applied to the nodes;

d) properties of the elements;

e) the loading to be analyzed.

The program output, at a minimum, consists of nodal point

deflection values and normally includes nodal forces and/or element stress values. CAL breaks this procedure down into a series of simple steps under the control of the user. It was designed to execute rapidly on small problems, so students can quickly see results of an analysis. There are options which allow the user to debug data without printing previously obtained results. Looping operations are also available. This allows a user to program iterative numerical algorithms, greatly expanding the usefulness of the program. In this version, CAL will solve problems with about 50 degrees of freedom (DOF).

The primary aim of the thesis work presented here was to modify CAL for use on the IBM 360/67 computer at the Naval Postgraduate School (NPS). The NPS version of CAL has both interactive and batch operating modes, and is nearly machine independent.

Most of this thesis effort was not involved in the numerical procedures used for calculations, but rather in the non-numerical areas of data input and processing. For this reason, numerical procedures will not be discussed. Subsequent chapters will provide:

a) a substantive discussion of some non-numerical techniques useful in writing scientific programs such as CAL;

b) a discussion of the internal organization of CAL-NPS;

c) instructions for the implementation of CAL on a different computer.

The appendices contain a listing of the FORTRAN code and an Instruction Manual for CAL-NPS.

Modifications to the program were carfully made to avoid changes in the instruction manual written by Professor Wilson. Ten commands have been added and three commands

have been extended for more flexibility in the interactive use of the program. The original instruction manual has been modified to reflect these changes and is reproduced in Appendix B. The author gratefully acknowledges Professor Wilson's permission to use the manual.

The non-numerical techniques discussed in Chapter II are this author's effort to explain how several state-of-the-art programming techniques work. It is hoped that readers will find this section beneficial in their own programming efforts. The CAL organization discussed in Chapter III is an excellent outline for general scientific programs. Additionaly, Chapter III provides details for writing user supplied subroutines. For readers who are interested only in how to use CAL, Chapter II and IV may be omitted.

II. NON-NUMERICAL TECHNIQUES IN FORTRAN

Chapter II is used to discuss FORTRAN programming techniques for writing general scientific programs. The reader is assumed to have some familiarity with the FORTRAN language and computer programming (i.e., completed CS2700 FORTRAN Programming or equivalent at NPS). After introductory remarks on the attributes of a scientific program, dynamic dimensioning is discussed in Section A, free and object time formats are discussed in Section B, data management is discussed in Section C, and finally, looping is discussed in Section D. The terms will be defined as encountered in these sections.

A general purpose program for the computer solution of a class of scientific problems should be simple to use, flexible and reliable. This requires a program that:

a) is modular, i.e., sections of program may be deleted, inserted or modified with ease;

b) has numerical methods that are stable and accurate for the type of problem encountered;

c) may require the user to have a knowledge of numerical methods necessary for the selection of the appropriate solution technique or boundary conditions but does not require knowledge of computer programming beyond the ability to prepare the input data for a program, initiate execution of a program, and create data files;

d) is not limited by array sizes in dimension or common statements;

e) permits iteration, i.e., the repeated execution of a user selected sequence of operations;

f) requires a minimum of central processor time and internal computer memory space (core) for execution;

A very useful method for meeting these requirements is to structure the program around the use of a problem oriented language. Such a language consists of a set of mnemonics representing each possible step in the general solution of the problem.

A mnemonic is a word that serves as a memory aid to identify some thing or some action. In FORTRAN, the mnemonic COS is used to represent the process of computing the cosine of an angle. All mnemonics can be thought of as representing a function subprogram, which can be very complex. The use of mnemonics to represent various operations in the formulation and solution of a particular problem is a very attractive method of writing a program for the general solution of a class of scientific problems. This technique promotes modularity and greatly simplifies use of the program. The mnemonic used for a particular operation or computation should be representative of the operation. For instance, a programmer might select the mnemonic SOLVE for the operation of computing the vector x from the matrix equation Ax = B where A and B are known. The mnemonic identifying a particular operation together with a list of arguments necessary for the computation is read from one data card. This card is followed by a series of data cards to provide data, not currently in core storage, for computation. The ability to enter the information in free format or to allow object time format specification dramatically reduces the work required to use the program.

References (1), (2), and (3) provide examples of problem oriented language programming. Apart from these few examples, there is very little written on the non-numerical techniques needed to write a program for the general solution of a scientific problem using a problem oriented

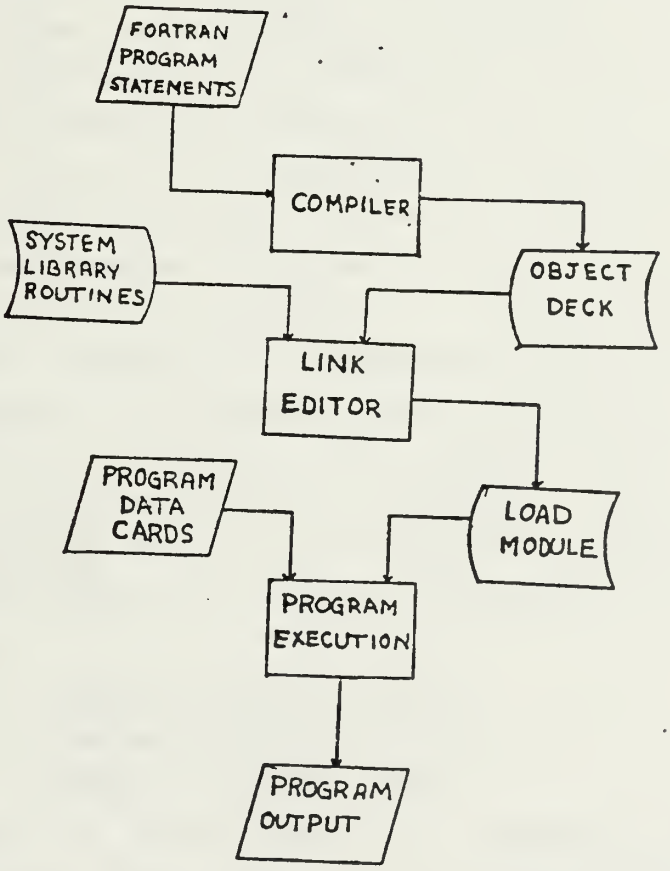
language for the solution. References (4) and (5) are useful exceptions and provide some very valuable information. The numerical techniques for execution time array dimensioning, execution time and free format, data management and the automated repetition of a user selected sequence of instructions will now be discussed in some detail.

A. DYNAMIC DIMENSIONING

In classical programming, array storage is reserved either in common or in dimension statements. Either way, the dimensions are usually set to the largest values envisioned for the type of problem under solution. When small or medium sized problems are solved, a considerable amount of core space is reserved but not used. Avoiding the wasted space normally requires re-doing the dimension and/or common statements in the entire program and then re-compiling the whole program.

Compilation is the first step in preparing a program for execution. In the compile step, the FORTRAN statements are interpreted to produce a set of machine language instructions, called an object deck, that the computer is capable of following. The next step is to link-edit the object deck. The link-editor collects all of the machine language instructions needed to read data, write, and evaluate functions called by the program; puts them in logical order with the object deck; and prepares an index to locate various sections of the program. The output from the link-editor is called the load module. The final step is the actual execution of the program. This is called the go step and consists of storing the load module in core then executing the instructions in sequence. Figure 1

demonstrates this process graphically. Usually it is possible to use a compiler that will optimize the machine language code to minimize the run time for a program in execution. Optimizing compilers take more time and require more core space to compile than do non-optimizing compilers. It is possible to compile and link-edit a program then store the load module on a mass storage device (magnetic tape or disk). This always results in saving central processor (CPU) time for subsequent program runs and can result in a significant reduction of the amount of core required.



Program Processing

FIGURE 1

The alternative to the classical style of programming is dynamic dimensioning. In order to understand the concept of dynamic dimensioning, it is necessary to have some appreciation for how a computer handles a common statement. Inside the computer, the common statement will cause the reservation of sufficient bytes of memory to store listed variables. A byte is a segment of a computer word which can contain either one alpha (hollerith) character or about two decimal digits. If the same common requires a different number of bytes in different subroutines, the largest requirement will be the one reserved. Any type of variable may occupy the reserved storage as long as the address of the starting byte of the variable is consistent with the type of variable. Different types of variables frequently have a different number of bytes in a word. For instance, a complex variable will normally have twice as many bytes per word as a real variable. To illustrate this point, consider a program where all variable names beginning with A are double precision (8 bytes), all variable names beginning with Z are complex double precision (16 bytes), and variables beginning with N are integers (4 bytes). The named common EXAMPLE might be listed as follows in different subroutines:

```
COMMON /EXAMPLE/ N(12)          (1)
COMMON /EXAMPLE/ A(3,2)         (2)
COMMON /EXAMPLE/ Z(3)           (3)
```

In each case the same number of bytes of storage are reserved (48) but the common has a significantly different type of variable! Introductory FORTRAN courses normally teach the student that a particular common should always be an exact duplicate each time it appears in the program

without much other discussion of the uses of common statements. The example lines above contrast sharply with this cautious style but can prove very useful in actual problem solving. Table 1 gives the address of the starting byte for each variable in EXAMPLE.

BYTE	VARIABLES
1	N(1),A(1,1),Z(1)
5	N(2)
9	N(3),A(2,1)
13	N(4)
17	N(5),A(3,1),Z(2)
21	N(6)
25	N(7),A(1,2)
29	N(8)
33	N(9),A(2,2),Z(3)
37	N(10)
41	N(11),A(3,2)
45	N(12)

Byte Addresses for Variables

TABLE 1

Note that N(3), A(2,1) and the imaginary portion of Z(1) all have the same byte as their starting address. Additionally, 48 bytes would have been reserved even if the array dimension of both (2) and (3) had been set at one since (1) still requires 48 bytes. One more feature of importance is that A(2,1), A(1,2) and A(3,2) contain the same information as the coresponding imaginary portions of the Z vector. This fact is quite useful in programming with complex variables.

The common EXAMPLE above demonstrates how a computer stores a two dimensional array but amplification may prove helpful. The right most subscript in a multiply dimensioned array is always the one that increases slowest as the array is going into computer storage. The address in memory of an element of a linear array is computed much faster than the address of an element from an array with multiple

subscripts. The address of the element A(I,J) of a two dimensional array can be computed in a corresponding linear array as follows:

$$L = ((J-1)*NR + I - 1)*IPR + 1 \qquad (4)$$

where

NR is the number of rows in the matrix

IPR is the ratio of bytes per word of the matrix to bytes per word of the linear array.

For example, compute the index in N of A(3,2) from the common EXAMPLE:

here I=3, NR=3, J=2 and IPR = 8/4 = 2

$$L = ((2-1)*3 + 3 - 1)*2 + 1 = 11$$

Compare this answer with the results in table 1.

Dynamic dimensioning is a process that utilizes the computer's ability to store different types of variables in the same common array. Array storage is reserved in blank common with a large, one-dimensional, integer array (hereafter called the main array) for all subscripted variables needed for a particular computation step. This is normally done in a very short main program. Problem size can be controlled by the dimension of the main array in the main program. The dimension of the main array in all subroutines is set at 1 and never changed. Typically, to change a problem size, two cards of a six card main program need to be altered. See figure 2 for an example. The main program needs to be compiled, but there is no need to use an optimizing compiler. The remainder of the program can be in

a load module on a mass storage device.

```
C-----MAIN PROGRAM
      COMMON MAX,L(6000)
      MAX = 6000
      CALL DRIVER
      STOP
      END
C-----SUBPROGRAM TO CONTROL EXECUTION
      SUBROUTINE DRIVER
      COMMON MAX,L(1)
      .
      .
      .
      CALL COMPUTE(L(N1),L(N2),...,N3,N4)
      .
      .
      .
      RETURN
      END
C-----SUBROUTINE FOR COMPUTATION
      SUBROUTINE COMPUTE(A,B,...,NROW,ICOL)
      DIMENSION A(NROW,1),B(1)
      .
      .
      .
      RETURN
      END
```

Dynamic Dimensioning Sample Program

FIGURE 2

The main program calls a subprogram which controls execution, reserves storage in the main array for subscripted variables, and provides the address of array arguments in the main array to the computation subroutines. This subprogram must also ensure that there is sufficient room in the main array before a subscripted variable is allowed to be stored. Boundary misalignment occurs if the type of variable being stored requires more than one integer word for storage, and the starting address of the subscripted variable in the main array is not an address that is compatible with allowable addresses for the variable being stored. Some compiliers automatically correct for

boundary alignment but often this is accomplished with a considerable penalty in the time required for execution. Consider, for example, that a real double precision variable on an IBM 360 computer requires two integer words for storage. A boundary misalignment will occur unless the double precision variable is at an odd integer word address counting from the first integer word in blank common. In figure 2, MAX is the first integer word and L(1) is the second word in blank common. L(2) is, therefore, the first address available for the storage of the double precision element. L(2) and L(3) are required for the storage of one double precision number. If the double precision variable started in L(1), it would be out of proper alignment for this type of variable. A simple way to compute a proper starting address is:

```
N1 = NSIZE + MOD( NVAR + NSIZE , IPR ) + 1
```

where

N1 is the starting address to be computed.

NVAR is the number of integer words used by the variables in blank common preceeding the main array, L.

NSIZE is the number of words in the main array that have been used.

IPR is the number of integer words required to store the variable being processed.

MOD(I,J) is an ANSI standard function which returns the remainder from (I / J).

A method to keep track of the starting addresses for subscripted variables will be discussed later. The amount of storage available may be compared with the amount required for storage of a subscripted variable as follows:

```
LEFT = MAX - ( N1 + NEL * IPR ) + 1
```

where

LEFT is the number of integer words remaining.

MAX is the number of integer words in the main array.

N1 is the starting address in the main array for the variable.

NEL is the number of elements in the variable. Note that when blanks are left between the end of an array and the start of the next array to compensate for boundary alignment, NEL of the leading array is effectively changed.

IPR is the number of integer words required per element.

Positive steps must be taken to prevent LEFT from becoming negative. One method to compute the number of words that have been used in the main array is

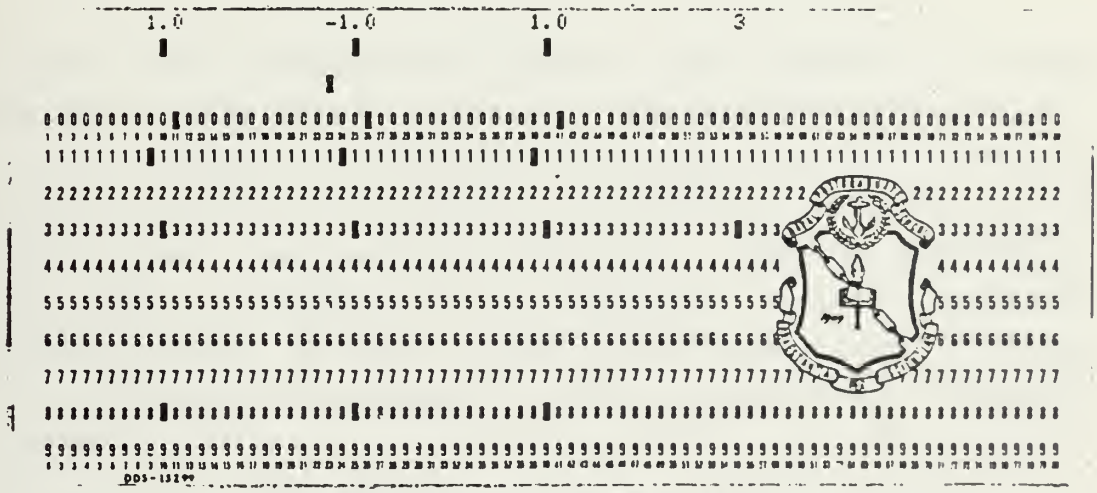
NSIZE = MAX - LEFT

where all variables are used as defined above.

Figure 2 is an example of some programming necessary to implement the dynamic dimensioning concept. The variable MAX and the dimension of the L array must have the same value in the main program. Outside the main program, the L array needs only to be dimensioned one since adequate storage is already reserved. In the control subprogram, N1 and N2 are used to provide starting addresses for subscripted variables to the computation subroutine. N3 and N4 are used to provide array dimensions. The dimension statement in the computation subroutines can use variables for array subscripts. Linear arrays and the final subscript of multiply subscripted arrays need only be set to one as shown in figure 2.

B. FREE AND OBJECT TIME FORMATS

Recall that in classical programming, data entered into the computer must be entered exactly in accordance with the format statement that has been compiled with the program. For instance, suppose that the coordinates and a reference number are required for a point in 3-space in format(3F15.5,I10). Figure 3 is the data card required for the point (1.0,-1.0,1.0) assigned reference number 3. Note that if the 3 is not in card column 55, the reference number assigned to the point will be wrong. When the input device is a terminal, the probability of making an error on entering data with this type of fixed format is high. Errors in entering data frequently require the user to restart the program and re-enter all the data to correct a small mistake.



Sample Fixed Format Data

FIGURE 3

Object time format (also called variable format) permits the user to enter the format for subsequent input or output operations as a part of the data deck at the time the

program enters execution. This means that it is possible to read an array prepared in (F10.0) format and an array prepared in (5E15.7) format without changing the format statement and recompiling the program.

Object time formatting is accomplished by reading a card containing the format for the data to follow, then reading or writing the data as specified in the format. A sample of the required programming to read data is:

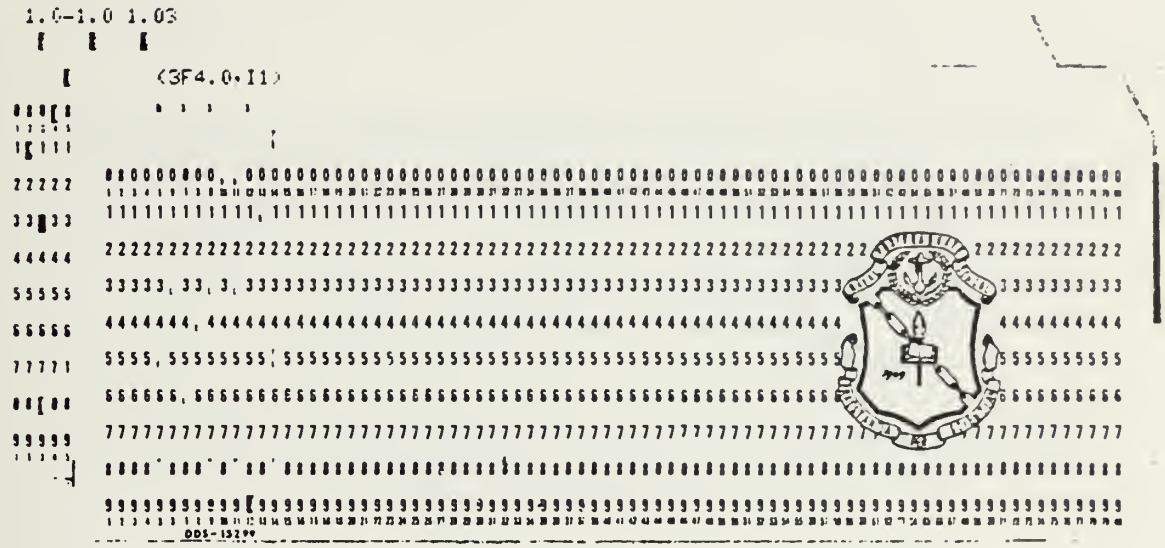
```
      DIMENSION FOR(20),A(3), ...
      .
      .
      .
100   READ(5,200) FOR
200   FORMAT(20A4)
300   READ(5,FOR) (A(I),I=1,3),J
      .
      .
      .
```

Statement 100 represents an ordinary read command in FORTRAN according to the format statement numbered 200. This format statement causes 80 columns of hollerith data to be read (4 columns each into 20 variables). Statement 300 causes 4 real numbers to be read into the vector A. However, instead of being read according to a numbered format statement contained in the program, these numbers are read according to the information contained in the variable FOR. FOR might contain:

```
(3F4.0,I1)
```

causing the coordinates of the point discussed above to be read as the vector A in format (3F4.0) and the reference number to be read as the integer J in format (I1). Figure 4 shows the cards required to enter the point and reference

number.



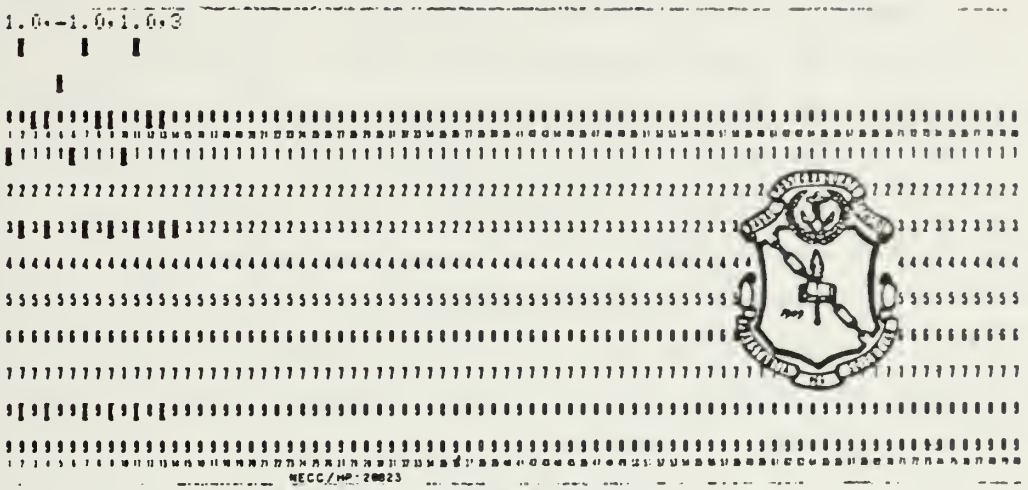
Sample Object Time Dimension Data

FIGURE 4

The first non-blank character on the data card containing the format must be an open parenthesis. The last non-blank character must be a close parenthesis. The characters in between must constitute a valid format for the data to be read or written.

Object time dimensioning allows the user to adjust formats to suit the data being input. However, if the user neglects to enter a format or enters one containing an error, the resulting problems can be frustrating. Free format relieves the user of the difficulties associated with using any type of predefined format. Figure 5 is an example of the data card required to enter the point and reference number discussed earlier. This example uses a comma (,) as

an end of field symbol and a blank ( ) as the end of record symbol.



Free Format Data

FIGURE 5

The first step of programming free-format input is to read the data card into an array called the card-image array. The data card must be read in format (80A1) so that the Jth element of the card-image array represents the character in column J of the data card. It is important to note that the value stored in the computer for a digit read as a hollerith character is different from the value stored for the same digit read as a number. The card-image array is then processed element by element to form the input variables. These input variables may be integers, real numbers or character strings, however, the variables must still be in the order expected by the program. If the expected input is a data card containing a step name and matrix argument list, a card containing real numbers will cause an error. Free format input allows the program and not the system error handling routine to determine appropriate corrective action.

The first step in processing an element of the card-image array is to identify the character stored in the element. How precise the identification must be depends on the application. The character being used as an end of field symbol and the character being used as an end of record must always be identified precisely. If, for instance, the expected data is a step name and matrix argument list, then the programmer might chose to identify all alphabetic characters as one type of symbol, all digits as a second type of symbol and all characters not otherwise identified as a third type of symbol. However, if the expected data contains a real number that may or may not have an exponent the choice of characters might be; 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, +, ., D, E, and others. The variable NSYM will be used to indicate the type of character.

The history of the processing is important in deciding what to do with a character. For instance, in the assembling of the real number 1.21, there are two types of character, digits and a decimal point. If the character encountered is a digit, the proper assembly action depends on whether the decimal point has occurred. If the decimal point has not occurred, the number being assembled must be multiplied by 10 and then the digit added to the number. On the other hand, if the decimal point has occurred, the digit must be divided by 10 then added to the number being assembled. The power of 10, N, is a counter representing the number of places to the right of the decimal this digit belongs. The varialbe IACT will be used to indicate the appropriate assembly action.

In addition to integral and fractional digits, a number may carry an algebraic sign and/or a sign in the exponent. The sign may occur at the beginning of the number or at the start of the exponent, however, a sign encountered elsewhere

will definetly be an error. It follows that for the assembly process of real numbers, the program performs one of the following operations: (a) sign identification, (b) integral digit assembly, (c) decimal point identification, (d) fractional digit assembly, and (e) exponent assembly. These processes are refered to as states. If the state is integral digit assembly and the character encountered is a sign, then obviously an error has occurred. On the other hand, if the character encountered is a decimal point, then there is no error but the state for the next operation needs to be changed to fractional digit assembly. A variable named ISTATE is introduced to indicate which one of the above operations the program last performed. Now, continuing with the assembly of a real number, the variable ISTATE may be assigned as follows:

ISTATE	Processing:
1	at the beginning of a Field.
2	after the beginning but before the decimal point.
3	after the decimal point.
4	after the exponent sign.
5	after an error has occurred in the field.

Again, for different applications, the programmer may define other states as needed.

The next step in processing a character from the card-image array is two-fold. The proper action to assemble the variable must be executed. This, of course, is given by the value of IACT. Also, if required, the state must be changed. A single integer can be used to represent both the next state and the assembly action required. For example, the information contained in ISTATE and IACT can be combined into a single variable, IPROC, by:

IPROC = IACT*100 + ISTATE

The information can be separated by:

IACT = IPROC/100

and

ISTATE = MOD(IPROC,100)

A matrix can be assembled that has the row index defined by ISTATE and the column index defined by NSYM. If an element of this matrix represents IPROC for the ISTATE and NSYM that define the element, then this matrix is an efficient method of programming the assembly task. The matrix so constructed is called the Symbol-State Matrix. Reference (4) contains futher discussion of Symbol-State matrices and their uses.

For illustration, consider the problem of reading a real linear array of length NEL. For simplicity, elements of the array may not have exponents. The state is identified as:

ISTATE	Processing:
1	at the beginning of the field.
2	before the decimal point.
3	after the decimal point.
4	after an error.

The steps that need to be programmed are:

a) Initialize the storage array, the symbol-state matrix, a hollerith translation table and the array pointers. A hollerith translation table is a vector that contains the hollerith character indicated by NSYM in the element with the index NSYM.

b) Read a card in A1 format into a temporary integer array.

c) Initialize the card column pointer called ICARD, the program state identifier (ISTATE), and the fractional digit counter called NCOUNT.

d) Identify the character occupying the ICARD column of the card-image array (NSYM) from the hollerith translation table.

e) Using NSYM and the current ISTATE as indices for entry in the Symbol-State matrix, called ISST, obtain IPROC (IPROC = ISST(ISTATE,NSYM). From IPROC, compute IACT and the new ISTATE.

f) Carry out the appropriate assembly action based on the value of IACT as follows:

1) Set a flag indicating the number is negative.

2) Assemble the digit into the integral part of the number (X = 10.0 * X + DIGIT).

3) Assemble the digit into the fractional part of the number (X = X + DIGIT/(10.0**NCOUNT)), and step the fractional digit counter (NCOUNT).

4) Print an error message. An action to compensate for the error may be included here.

5) Store the element in the storage array. If the array is filled, return; otherwise, reset NCOUNT and continue. If the symbol causing this action is EOR, reset ICARD and continue at step B.

Note that a plus sign or decimal point changes the state of the program but does not require an assembly action. After the assembly action above is complete, proceed to step 6.

6) Increment ICARD and test for the logical end of record. If ICARD is greater than the record length, reset ICARD, execute step f.5 and continue at step b. If ICARD is

less than or equal to the record length, continue at step d.

SYMBOL / STATE	COLUMN / ROW	DIGIT 1	+ 2	- 3	. 4	EOP 5	EOR 6	OTHERS 7
BOP/BOR	1	202	602	102	602	501	501	404
DIGIT BEFORE DECIMAL	2	202	404	404	603	501	501	404
DIGIT AFTER DECIMAL	3	303	404	404	404	501	501	404
ERROR	4	604	604	604	604	601	601	604

SYMBOL - STATE TABLE

TABLE 2

Table 2 is a Symbol-State matrix that the programmer might use to accomplish the variable assembly described above. The table presumes that the action to compensate for an error is to set the element equal to 0.0 (or some other value) and execute step 5. Action 7 is assumed to be the same as 5 except it allows for differentiating between an end of record symbol and an end of file symbol with a test

on the value of IACT. This table does not indicate an error if there is no decimal point. Instead, the decimal point is assumed after the last digit of the field. Additions to the Symbol-State Table or modifications to the logic are not difficult once the concept is understood.

Now consider the problem of assembling a character string, for instance, as a matrix name. If there are 4 bytes per integer word, then one element of the card-image array may contain:

'S'	bl	bl	bl

where "bl" represents the blank character. The byte containing the hollerith character S from the card-image array must be moved into the appropriate byte of the character string variable being assembled. This is not a trivial problem. ANSI FORTRAN does not support byte manipulation. Major computer manufacturers have added features to their FORTRAN which allow byte manipulation for string assembly. CDC allows for byte manipulation with MASK and SHIFT operations. In IBM FORTRAN the job can be done with a subroutine as follows:

```
      SUBROUTINE SHIFT(A,B,I,J)
      LOGICAL*1 A(1),B(1)
C-----THIS SUBROUTINE MOVES THE JTH BYTE OF
C     VARIABLE B INTO THE ITH BYTE OF
C     VARIABLE A.
      A(I) = B(J)
      RETURN
      END
```

The next update of the ANSI FORTRAN Standard tentatively includes variable word size specification with a "CHARACTER*n" declaration, where n is an integer. If the change materializes then the above subroutine will work for any machine by changing LOGICAL*1 to CHARACTER*1.

C. DATA MANAGEMENT

The comments on data management have been restricted to the management of data storage in core. Only one of several alternatives is discussed and the management system presented is not necessarily the most efficient method. It is advocated because it represents a straight forward approach and one does not have to be a computer scientist to implement the procedure.

The problem of in core data management can be reduced to the problem of storing, finding and deleting arrays in the main array mentioned previously. One way of organizing the main array is to store an array directory at the start of each array in the main array. The array directory needs to contain the following information:

a) The number of elements in the array.

b) The precision of the array (integer words/element).

c) A unique identification for the array.

d) The number of rows and/or the number of columns in the array.

Diagram of Array Storage

The process of reserving storage for an array should:

a) Ensure adequate space is available in the main array. Processing must be interrupted for resolution of the problem if sufficient room is not available.

b) Adjust NSIZE to compensate for the additional

array.

c) Create and store the array directory based on information from the calling program.

d) Check boundary alignment and adjust NEL for the previous array if necessary. It is possible to adjust NEL of the current array so that any subsequent array will be on a proper boundary no matter what the precision of the subsequent array. This is a simple solution but does make some available space unavailable.

e) Return the main array address for the first element of the array to the calling program.

Locating an array requires searching the array directories for a match with the identifier of the array. One method of doing this type of matching is:

```
IF(COMP(L(N),II)) GO TO nnn
```

where

N is the address, in the main array, of the first word of the array identifier being tested.

II contains the name to be matched.

nnn is the statement number that is branched to if a match is found.

COMP is a function subprogram defined as follows:

```
      FUNCTION COMP(I,J)
      DIMENSION I(3),J(3)
      LOGICAL COMP
      COMP = .FALSE.
      DO 10 K = 1,3
         IF(I(K) .NE. J(K)) RETURN
   10 CONTINUE
      COMP = .TRUE.
      RETURN
      END
```

This example assumes that three integer words are used to contain the array identifier. If the array is found, the main array address of the starting element and the directory information needs to be returned to the calling program. If the array is not found, processing should be interrupted for

resolution of the error.

The motivation for providing a method of deleting arrays is two-fold. If matrices are not stored with unique names, the locating system described above will only find the first array in storage whether or not it is the array needed. By using the delete operation under program (vice user) control, it is possible to ensure each array name is unique at the time it is created. The second reason for having a delete capability is that when an array has served its purpose, deletion under either program or user control allows the storage to be freed for other uses.

It is advantageous to leave all free storage postions at the end of the alocated storage. The simplest way to do this is to identify, in the main array, the address of the first position used by the array to be deleted (N1), and the first element of the next array in storage (N2), then:

```
      N3 = N2 - N1
      DO 10 I = N1,NSIZE
10      L(I) = L(I+N3)
      NSIZE = NSIZE - N3
```

Note that if the directory is stored preceeding the array, then N1 would refer to the first element of the directory. In this case an alternate way of computing N3 is:

```
N3 = NEL*IPR + NDIR
```

There is no reason to interrupt processing for error resolution when an array is not found to be deleted. It is helpful to print a message when an array is actually deleted especially if the DELETE operation is initiated by the program, for instance, to prevent duplicate array names.

The more complicated storage schemes for banded or skyline storage of arrays is also possible with this system. Banded and

Skyline storage schemes make more efficient use of storage by simply not storing many of the matrix elements

that are zero. The skyline storage algorithm is the most storage efficient of the two types. Reference (1) contains a substantive discussion of the skyline storage method, and examples of matrix manipulation subroutines for use with the skyline algorithm. Suffice it here to say that the skyline storage alogrithm requires the creation of two vectors. One is a vector of the elements from the matrix that are actually stored. The second vector contains the indices in the first vector of the diagonal elements of the matrix. For this case, it is convenient to use the same directory for both vectors. If there are NEL elements under the skyline, each element takes IPR integer words and there are NR rows in the matrix, then the storage required is

NDIR + NR + NEL * IPR

a typical block of the main array might look like

DIRECTORY	DIAGONAL ELEMENT INDICES	STORED ELEMENTS

The above presents a straightforward approach to data management in core. It is codeable in ANSI FORTRAN IV by an individual familiar with the basics of the language. It does not require a professional programmer for implementation.

D. LOOPING

The capability to repetitively execute a series of instructions (looping) is an important tool in problem solution. Frequently, for non-linear problems, there is no direct method of solution. An iterative scheme is normally employed to solve this type of problem. Brute force iteration is possible with any program by making multiple

runs of the program with suitable alteration to the input data for each run. This is very wasteful of both the user's time and computer time. On the other hand, if looping is possible, the user can program an iteration scheme using the commands available, then place the series of commands in a loop. A relatively simple method of providing a looping capability is to store the commands of the loop as a matrix in the main array. Then, with appropriate pointers, it is possible to execute a series of instructions repetitively from memory, just as if they were coming from the input device. Details of the method of looping used in the program CAL are contained in Chapter III.

A particularly attractive advantage of looping is the ability to iterate for selected eigenvalues of a matrix. This ability permits one to approximate the number of significant digits in the computer soluton of a problem as follows:

$$NSD = NDA - ALOG10(EMAX/EMIN)$$

where

NSD is the number of significant digits.

NDA is the number of digits available in the word size.

EMAX is the maximum eigenvalue of the matrix.

EMIN is the minimum eigenvalue.

ALOG10 is the ANSI standard function for the logarithm to the base 10.

This approximation holds for positive, definite, symmetric matrices. Computer results for problems where NSD approaches 0 should be viewed with extreme skepticism.

III. CAL ORGANIZATION

This chapter provides a general overview of the operation and organization of CAL. It is intended to provide sufficient information to permit users to program subroutines for use in CAL and to operate the CAL system sensibly.

CAL is a modern computer program written in the FORTRAN IV programming language. It was written as a teaching aid for illustrating the direct stiffness method of structural analysis. In addition to extensive linear algebra capabilities, the program provides several analytical alternatives for both static and dynamic analysis of elastic structures.

CAL execution is flexible, controlled by user selection of operations in a logical sequence (not unique) from the operations available in the program. The input data deck is a sequence of modules. The first card of each module contains the name of the requested operation, a list of matrix argument names, and integer parameters used in that operation. Comments may be placed on the card following a blank.

The operation card looks like this:

OPERATION,M1,M2,...,M9,N1,...N4 COMMENTS

M1 through M9 are matrix argument names. A matrix argument name consists of up to 8 alpha-numeric characters, the first being alphabetical. N1 throuch N4 are positive integers. An operation card may use from zero through nine matrix arguments and/or from zero through four integers. If required, the operation card is followed by a sequence of data cards containing numerical information used for the step. Some features of the output from CAL are also

controlled by user selectable operations. Details of the operations available and how to execute CAL at NPS are presented in Appendix B.

CAL is logically divided into four segments. The main segment contains the main program and service subroutines used commonally by all other segments. In subsequent descriptions, the main segment will be referred to as CAL. Among other things CAL contains the subroutines to deliver the next operation and the subroutines for data management. The three remaining segments will be referred to as GROUP 1, GROUP 2, and GROUP 3.

GROUP 1 contains subroutines which perform matrix manipulations, i.e., load, print, multiply, etc. GROUP 2 contains subroutines associated with formulation of the static problem and display of the computation results. For example, there are subroutines to:

a) input nodal geometry;

b) input boundary conditions;

c) input loading conditions;

d) form element stifness and mass matrices by several different methods;

e) combine element matrices into global matrices;

f) display results.

Finally, GROUP 3 contains subroutines associated with dynamic analysis. Two methods of evaluating the second order equations of motion, eigen analysis, and printer plotting routines are available.

Matrix storage in CAL is done dynamically as described in Chapter II. It is not possible to state with precision the maximum problem size. Experience shows that with the default parameters of the NPS version, static analysis problems are limited to approximately 48 degrees of freedom (DOF). Dynamic analysis problem size is controlled by both

the system DOF and the number of displacement vectors to be calculated. For a 25 DOF system, about 100 displacement vectors can be calculated.

All arrays and matrices in CAL are stored in a one dimensional matrix specified in blank common as L(XXXXX). XXXXX represents the total storage reserved for subscripted variables. Each array is preceeded by a directory which contains:

1) the number of elements in the array (NEL).

2) the number of integer words required to store an element (IPR),

3) the number of columns in the array,

4) the number of rows in the array,

5) the first four characters of the matrix name,

and 6) the last four characters of the matrix name.

An array uses (NEL*IPR + 6) integer words of storage. Larger problems can be solved by increasing the size of the L array in the main program. The variable MAX must be set to the current dimension of the L array. This data management system is described in Chapter II. CAL uses three subroutines for the data management sub-system. There is a subroutine called LIST which is used to reserve storage for new matrices as they are created. The calling arguments are, in order, NM, NR, NC, IPR, and IERR. NM is an array name assigned by the user. Array names must start with an alphabetic character and conatin 1 to 8 alpha-numeric characters.

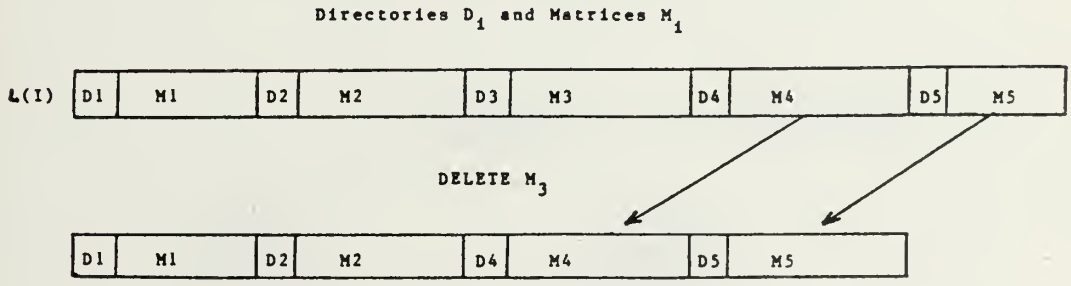
Since the name, NM, is used only in the directory, there is no reason to conform to FORTRAN name conventions. Thus, names beginning with the characters I through N may be assigned for real matrices with impunity. Call the stiffness matrix K, the mass matrix MASS and the nodal coordinate array NODES. All variables are treated as real,

double precision numbers unless clearly specified as integers in the command description.

NR and NC are respectively, the number of rows and the number of columns for the matrix to be stored. IPR is the number of integer words required to store an element. IERR is an error parameter. If IERR is not equal to 1, then an error has occurred during the list operation.

The subroutine LOCATE is used to locate arrays in the L array. The calling arguments are, in order, NM, NA, NR, NC, and IERR. NM, NR, NC, and IERR are used as described above. NA is the index in the L array for the first element of the array. In a subroutine call, L(NA) is used to pass the matrix NM to and from the called subroutine.

The remaining data management subroutine is DELETE. It has a single calling argument. NM is used as discussed previously. DELETE removes the matrix NM from the L array and frees the storage taken by NM at the end of the L array. Figure 7 illustrates this process.

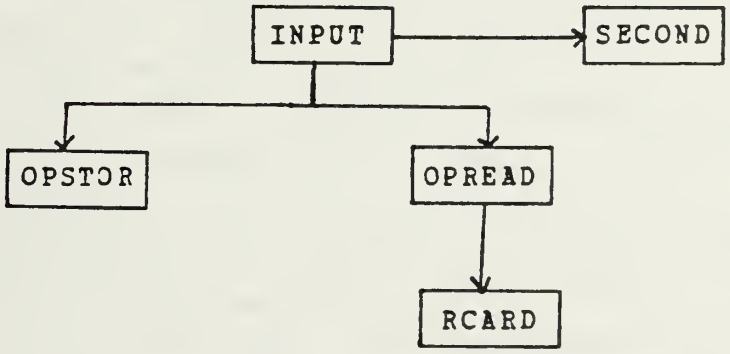


One Dimensional Array Storage

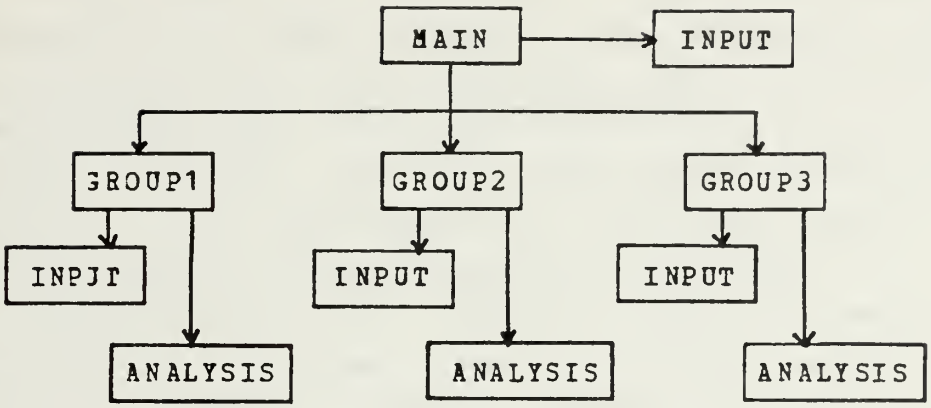
FIGURE 7

Now consider once more the function of the main program

segment CAL. In addition to the data management subroutines described above, the CAL segment contains four subroutines used to deliver the next operation to the calling program segment, and a timing subroutine. The subroutine INPUT determines whether the next operation is part of a loop or a new command from the input device. If the next operation is not part of a loop, INPUT calls the subroutine OPREAD. In turn, OPREAD calls the subroutine RCARD to read and interpret the free format information of the next command. Free format data input is discussed in Chapter II. If the command initiates looping, then OPREAD calls RCARD until all operations in the loop have been read. As operations are received by OPREAD, this subroutine stores them row-wise in the L array. After the last operation of the loop has been read, OPREAD calls LIST to prepare the directory. INPUT calls OPSTOR to provide each command in sequence from the loop matrix in the L array until the loop operations are complete. The subroutine SECOND is called by INPUT to determine the amount of time used in each computation step. A block diagram of the connections is:



A block diagram of the total system follows:



From this example, it is apparant that the program is organized so that only one group at a time needs to be resident in the core with CAL during execution. Thus, an overlay structure can be used which permits CAL to operate in a very small computer system.

Although CAL can operate in a small (64K) computer system, a mass storage device (magnetic tape or disk) must be available both to store program overlays and for use as a scratch pad during structural analysis operations. Element stiffness and mass matrices are written out on a mass storage device as they are created, then read back into the computer memory as needed for assembly into the global matrices. This method minimizes the amount of storage required in the core. Space is required to store the matrices only an element at a time, no matter how many elements are used.

The NPS version of CAL also contains commands which permit a user to stop execution before the end of a problem then resume at a later time. The operations also use a mass storage device to read or write the contents of the L array and certain other parameters.

One of the features of CAL which makes it so flexible is the availability of looping. Loops can be nested up to

five deep. Loops are initiated by the LOOP command and terminated by the NEXT command. For operations within a loop which require data, the data cards must appear in proper sequence, but after the last NEXT card of the loop. An example is shown with the loop command description in Appendix B. A skip command is available which allows selective skipping of operations within a loop.

A second feature of CAL which gives it really great flexibility is that user coded subroutines can be called under program control. GROUP 1 contains two operation names reserved for user coded subroutines. These names are USERA and USERB. A user coded subroutine might be used, for instance, to compute equivalent nodal forces for a distributed load.

Two subroutines are needed for a user operation. The actual numerical operation is coded normally in a subroutine with any name not already used in the CAL program. A buffer subroutine must then be written to interface the numerical computation with the CAL data management system. To illustrate the technique of interface, consider the familiar example of matrix multiplication (already available in CAL). Symbolically the problem is to compute C where C = A*B. The basic algorithm for matrix multiplication is

$$C(I,J) = A(I.K)*B(K,J)$$

A subroutine for the job might be:

```
      SUBROUTINE MULTIPLY(A,B,C,NRA,NCA,NCB)
      DIMENSION A(NRA,NCA),B(NCA,NCB),C(NRA,NCB)
      DO 20 I=1,NRA
      DO 20 J=1,NCA
      X = 0.0
      DO 10 K=1,NCA
   10 X = X + A(I,K)*B(K,J)
   20 C(I,J) = X
```

```
      RETURN
      END
```

The operation card might be selected as:

```
      USERA,M1,M2,M3  COMMENTS
```

where M1, M2, and M3 are respectively the matrix argument names for the dummy arguments A, B, and C. The recommended steps to be programmed in the buffer subroutine named USERA are:

a) locate M1 and M2;

b) ensure the number of columns in A is equal to the number of rows in B;

c) call the DELETE subroutine to ensure that a matrix with the same name as M3 does not already exist in storage;

d) call LIST to reserve storage for M3;

e) test IERR to ensure that no errors have occurred in the above steps;

and f) call subroutine MULTIPLY to complete the operation;

At the minimum, steps a, d, and f must be programmed. Here is a possible subroutine to meet the requirement.

```
      SUBROUTINE USERA(IERR)
      COMMON MAX,NDP,L(1)
      COMMON /CARD/ INHOL(3,10),N(4)
      CALL LOCATE(INHOL(1,2),IA,NRA,NCA,IERR)
      CALL LOCATE(INHOL(1,3),IB,NRB,NCB,IERR)
      IF(NRA.NE.NCA) IERR= 2
      CALL DELETE(INHOL(1,4))
      CALL LIST(INHOL(1,4),NRA,NCB,NDP,IERR)
      CALL LOCATE(INHOL(1,4),IC,NRA,NCB,IERR)
      IF(IERR.NE.1) RETURN
      CALL MULTIPLY(L(IA),L(IB),L(IC),NRA,NCA,NCB)
      RETURN
```

END

LOCATE, LIST, and DELETE are used as described previously. Blank common appears so that USERA has access to the L array and the parameter NDP. The variable NDP is initialized at 2, the number of integer words required to store a double precision variable. The named common CARD is initialized by RCARD or OPSTOR. The INHOL array contains the operation name and the matrix argument names. Each name is stored columnwise, i.e., column 1 has the operation name (USERA in this case), column 2 has the name of thematrix argument M1, etc. Row 1 elements have the first four characters, and row 2 elements contain the remaining four characters of the respective argument. Row 3 is not used in the NPS version of CAL. In the first call to subroutine LOCATE, INHOL(1,2) provides the name assigned by the user to matrix argument M1. On return from LOCATE, IA will be the index in the L array of the first element of M1. IB and IC respectively provide the same information for M2 and M3. Other variables are used as discussed previously.

Now, generalizing the procedure of the above example, the user must program two subroutines to define a user operation for CAL. One subroutine performs the operation, and the second acts as a buffer between CAL and the operation. Two names are available, USERA and USERB, for the buffer subroutine. Both have a single passing argument, the parameter IERR. The program assumes an error has occurred when IERR takes on a value other than 1. The buffer subroutine must:

a) locate matrix arguments designated for the operation,

b) reserve storage for arrays created by the operation,

c) pass the elements of the L array for the matrix

parameters used in the operation.

In addition, it is recommended that the buffer subroutine:

a) ensure that the matrix arguments to be used are compatible with the operation, i.e., square, symmetrical, etc.

b) call delete with names of matrices to be created prior to reserving storage. This will prevent matrices with duplicate names.

c) test IERR to ensure no error has occurred prior to calling the operation subroutine.

The operation subroutine can be coded with normal FORTRAN techniques.

In this chapter, the internal organization of CAL has been described, along with several important features of the program. Most of the non-numerical procedures described in the preceeding chapter are illustrated in CAL. This chapter has highlighted the flexibility of CAL and provided an example to assist users in coding their own operations to be executed by CAL.

IV. IMPLEMENTING CAL ON A DIFFERENT COMPUTER

In this chapter, the procedure to convert CAL for use on a different computer system is discussed. The NPS version of CAL has been organized to minimize the difficulty associated with implementing the program on a new computer. There remains, however, some things that are machine dependent.

The following information is required for the new system.

a) How many characters can be stored in one integer word?

b) How many integer words does it take to store a real variable? For structural analysis, a real variable should contain at least 12 significant figures.

c) What method can be used to manipulate bytes?

d) How is elapsed CPU time computed?

The answers to the above questions determine the complexity of the conversion task.

A. IBM FORTRAN STATEMENTS

There are a few statements in this version of CAL solely in the IBM FORTRAN Language. The statement "IMPLICIT REAL*8(A-H,O-Z)" makes all real variables double precesion. This statement appears in almost every subroutine. It should be replaced by an appropriate statement when using another computer. The calls to ERRSET suppress printout of error messages. These statements appear together in subroutine CAL1 and must be removed. They do not need to be replaced. The call to SETIME in the main program should be removed for use on non-IBM machines.

B. TIME COMPUTATION

There is no standard method of computing elapsed CPU time. The subroutine SECOND must be rewritten to compute elapsed CPU time in seconds for the new system. The library of subroutines for the computer system should have a suitable routine.

C. BYTE MANIPULATION

As previously mentioned, there is no standard way to shift bytes in a variable. The subroutine MOVEB will work if one byte logical variables are available. If this is not the case, than MOVEB must be rewritten using a byte manipulation technique suitable for the computer system.

D. OPERATION AND MATRIX NAMES

In this version, names are stored four characters to a variable since the IBM 360/67 computer uses four bytes per standard integer word. Names are stored column-wise in vectors of three elements. The parameter NH must be set to the number of elements required for storage of a name on the new system. LBYTE must be set to the number of characters per integer word. NH should be set such that NH*LBYTE at least 6. Both of the parameters are set in the BLOCK DATA subprogram. Data statements initialize operation names in the BLOCK DATA subroutine and in all three of the GROUP subroutines. All these data statements must be adjusted so that they initialize LBYTE characters per element. Format statements for write commands with output in format A4

should be changed. For the most part the output format wAd should be changed so that w = NH and d = LBYTE. Other uses should be apparent to the programmer.

E. BOUNDARY ALIGNMENT

There are three potential areas which may cause boundary alignment problems. NDP is set in the main program to the number of integer words needed to store a real variable. NDIR is the number of integer words used for a matrix directory. The first possible problem area is the relation between NDIR and NDP. If NDIR is not evenly divisable by NDP, add the remainder to the equation for NDIR in the BLOCK DATA Subroutine. The second possible problem area is in the Subroutine LIST. This subroutine contains a test to ensure the number of elements reserved for a single precision array is evenly divisible by NDP. If NDP is more than 2, the test is not valid. A better test would be

```
IF(NP.EQ.1) I(1) = NR * NC + MOD(NR*NC,NDP).
```

Finally, if NDP is greater than 2, then blank common must be adjusted so that there are NDP integer variables preceeding the L array in the main program and all subroutines where blank common appears.

V. CONCLUSIONS AND RECOMMENDATIONS

CAL provides a flexible tool for teaching modern sturctural analysis. The general matrix operations make it useful in the area of linear algebra as well as structural analysis. The use of CAL is highly encouraged.

A. RECOMMENDED MODIFICATIONS

A graphical display capability should be incorporated in CAL as soon as the equipment becomes available. It would be espically helpful to have a display of the element forces from the FORCE operation. Additionally, incorporation of heat transfer options into the program should be considered. The heat transfer capability would be a valuable tool for students in the department.

B. OTHER APPLICATIONS

The organization of CAL provides an excellent outline for development of other major analytical programs. The storage scheme can be simply modified to permit matrix storage using the skyline algorithm. Large problems can then be accomodated by incorporating existing algorithms for an out-of-core equation solver.

```
C------MAIN PROGRAM                                                    STO000010
C------SET PROGRAM CAPICITY                                           STO000020
      COMMON MTOT,NDP,L(6000)                                         STO000030
      COMMON /ERROR/ NERR,MODE,NTIME                                  STO000040
      MTOT = 6000                                                     STO000050
C------NDP IS NUMBER OF COMPUTER WORDS USED BY A REAL VARIABLE.       STO000060
      NDP = 2                                                         STO000070
C                                                                     STO000080
C      CALL SETIME                                                    STO000090
C                                                                     STO000100
C------SETIME IS IBM 360 ROUTINE TO INITIALIZE CPU TIMER.             STO000110
C                                                                     STO000120
      CALL CAL1                                                       STO000130
      STOP                                                            STO000140
      END                                                             STO000150
C                                                                     STO000160
C------THE CAL PROGRAM IS A COMPUTER ANALYSIS LANGUAGE FOR THE STATIC  STO000170
C------AND DYNAMIC ANALYSIS OF STRUCTURES.  PROBLEM SIZE IS CONTROLLED STO000180
C------BY THE DIMENSION IN BLANK COMMON AND THE VARIABLE MTOT.         STO000190
C------ALL PROBLEM ARRAYS AND THIER DIRECTORIES ARE STORED IN BLANK    STO000200
C------COMMON.  STRUCTURAL ANALYSIS OPERATIONS REQUIRE SCRATCH STORAGE.STO000210
C------THE PROGRAM IS SET TO USE FILE FT01F001 FOR THIS.               STO000220
C------PROGRAMMED BY PROF EDWARD L. WILSON, CIVIL ENGINEERING DEPT,    STO000230
C------UNIVERSITY OF CALIFORNIA, BERKELEY, CA.                         STO000240
C                                                                     STO000250
      SUBROUTINE CAL1                                                 STO000260
      IMPLICIT REAL*8 (A-H,O-Z)                                       STO000270
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR           STO000280
      COMMON /NAMES/ LOOP(3),NEXT(3),LSKIP(3),LNAME(3),NSTART(3),     STO000290
     1 LSTOP(3)                                                       STO000300
      COMMON /LOOPD/ LA,IN,INDEX(5),LSTART(5),IJKLM(5),NW             STO000310
      COMMON /CARD/ INHOL(3,10),N(3),S1,S2                            STO000320
      COMMON /ERROR/ NERR,MODE,NTIME                                  STO000330
      LOGICAL COMP                                                    STO000340
C                                                                     STO000350
C------SET INITIAL CONDITIONS                                         STO000360
C                                                                     STO000370
      CALL ERRSET(208,256,-1,1,1)                                     STO000380
      CALL ERRSET(207,256,0,1,1)                                      STO000390
      CALL ERRSET(209,256,0,1,216)                                    STO000400
C                                                                     STO000410
C------ERRSET IS ERROR HANDLING ROUTINE FOR IBM 360 MACHINES.  THIS   STO000420
C------CALL SUPPRESSES PRINTOUT OF UNDERFLOW ERROR MESSAGES (IHC208) AND STO000430
C------TRACEBACK OF SEVERAL OTHER ERRORS.                             STO000440
C                                                                     STO000450
      NW=10*NH+4                                                      STO000460
  400 LA = 0                                                          STO000470
      IN = 0                                                          STO000480
      IERR = 1                                                        STO000490
      CALL DELETE(LNAME)                                              STO000500
      CALL INPUT(IERR)                                                STO000510
      IF(IERR .NE. 1) GO TO 500                                       STO000520
      LAST=1                                                          STO000530
      GO TO 110                                                       STO000540
C-----  SEARCH GROUPS OF OPERATIONS FOR INPUT OPERATION               STO000550
  100 IF(LAST.EQ.1) GO TO 300                                         STO000560
  110 CALL GROUP1(LAST,IERR)                                          STO000570
      IF(LAST.EQ.2) GO TO 300                                         STO000580
      IF (IERR .NE. 1) GO TO 500                                      STO000590
      CALL GROUP2(LAST,IERR)                                          STO000600
      IF(LAST.EQ.3) GO TO 300                                         STO000610
      IF (IERR .NE. 1) GO TO 500                                      STO000620
      CALL GROUP3(LAST,IERR)                                          STO000630
```

```
      IF (IERR .NE. 1) GO TO 500                                        STO00640
      GO TO 100                                                         STO00650
  300 WRITE(NERR,3000)                                                  STO00660
  500 IF(MODE .NE. 1) GO TO 400                                         STO00670
      NO = 0                                                            STO00680
  500 CALL RCARD(IERR)                                                  STO00690
      IF(COMP(INHOL(1,1),NSTART))GO TO 400                              STO00700
      IF(COMP(INHOL(1,1),LSTOP)) STOP                                   STO00710
      GO TO 600                                                         STO00720
 3000 FORMAT (30HOOPERATION UNDEFINED OR BLANK   )                      STO00730
      END                                                               STO00740
      BLOCK DATA                                                        STO00750
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO00760
      LOGICAL INDIC                                                     STO00770
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR,INDIC       STO00780
      COMMON /RECON/ IN(80),INDIGI(80),ITAB(5,4),NUM(10),LBYTE          STO00790
      COMMON /NAMES/ LOOP(3),NEXT(3),LSKIP(3),LNAME(3),NSTART(3),       STO00800
     1 LSTOP(3)                                                         STO00810
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)            STO00820
      COMMON /ERROR/ NERR,MODE,NTIME                                    STO00830
      COMMON /PSAVE/ NUMNP,NEQ,NPROP,NUMEL,NTRUSS,NT,NSAVE             STO00840
C-----NH IS NUMBER OF WORDS NEEDED TO CONTAIN 6 HOLLERITH CHARACTERS.   STO00850
C-----NDIR = NH + 4*NSP                                                 STO00860
      DATA NO/0/,NARA/0/,NSIZE/1/,NSP/1/,NH/2/,NDIR/6/,INDIC /.TRUE./   STO00870
C-----NREAD IS READ FILE DEVICE NUMBER.                                 STO00880
C-----NWRITE IS WRITE FILE DEVICE NUMBER.                               STO00890
      DATA NREAD/5/,NWRITE/6/                                           STO00900
      DATA NUM/2H1 ,2H2 ,2H3 ,2H4 ,2H5 ,2H6 ,2H7 ,2H8 ,2H9 ,2H0 /       STO00910
      DATA ITAB/2*500,205,104,205,500,303,405,303,405,2*102,2*104,      STO00920
     1 6*500/                                                           STO00930
C-----LBYTE IS NUMBER OF BYTES PER  INTEGER WORD.                       STO00940
      DATA LBYTE/4/                                                     STO00950
      DATA LOOP /4HLOOP,4H    ,4H    /                                  STO00960
      DATA NEXT /4HNEXT,4H    ,4H    /                                  STO00970
      DATA LSKIP /4HSKIP,4H    ,4H    /                                 STO00980
      DATA LNAME/4HLINA,4HME   ,4H    /                                 STO00990
C-----NT IS FILE DEVICE NUMBER FOR SCRATCH TAPE.                        STO01000
C-----NSAVE IS FILE DEVICE NUMBER FOR SAVE FILE.                        STO01010
      DATA NT/1/,NSAVE/2/                                               STO01020
      DATA NSTART/4HSTAR,4HT   ,4H    /                                 STO01030
      DATA LSTOP /4HSTOP,4H    ,4H    /                                 STO01040
C-----NERR IS FILE DEVICE NUMBER FOR ERROR MESSAGES.                    STO01050
C-----MODE SELECTS INTERACTIVE OR BATCH MODE OF OPERATION.              STO01060
C     MODE=1 FOR BATCH PROCESS OR MODE .NE. 1 FOR INTERACTIVE PROCESS.  STO01070
      DATA NERR/6/,MODE/2/                                              STO01080
      DATA NTIME/0/                                                     STO01090
      END                                                               STO01100
      SUBROUTINE SECOND(T)                                              STO01110
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO01120
```

```
      COMMON /ERROR/ NERR,MODE,NTIME                                    ST001130
C-----ROUTINE TO COMPUTE ELAPSED CPU TIME IN SECONDS.                   ST001140
C-----THIS ROUTINE WILL HAVE TO BE CHANGED TO WORK ON OTHER MACHINES.    ST001150
C-----STATEMENTS FOR CP/CMS AT NPS, MONTEREY, CA.                       ST001160
      DIMENSION ITIME(6)                                                ST001170
      CALL IXCLOK(ITIME)                                                ST001180
      T = DFLOAT(ITIME(6))/768.0D+2                                     ST001190
C                                                                       ST001200
C-----STANDARD IBM 360 TIMER PROGRAM.                                   ST001210
C     CALL GETIME(IET)                                                  ST001220
C     T = DFLOAT(IET)*2.6D-5                                            ST001230
C                                                                       ST001240
      RETURN                                                            ST001250
      END                                                               ST001260
      SUBROUTINE MOVEB(A,I,B,J)                                         ST001270
C                                                                       ST001280
C-----THIS SUBROUTINE MOVES THE JTH BYTE OF VARIABLE B INTO THE         ST001290
C-----ITH BYTE OF VARIABLE A.  IT MAY HAVE TO BE REWRITTEN TO           ST001300
C-----WORK ON OTHER MACHINES.                                           ST001310
C                                                                       ST001320
      LOGICAL*1 A(1),B(1)                                               ST001330
      A(I) = B(J)                                                       ST001340
      RETURN                                                            ST001350
      END                                                               ST001360
      SUBROUTINE INPUT(IERR)                                            ST001370
      IMPLICIT REAL*8 (A-H,O-Z)                                         ST001380
      LOGICAL INDIC                                                     ST001390
      COMMON MTOT,NDP,L(1)                                              ST001400
      COMMON /LOOPD/ LA,IN,INDEX(5),LSTART(5),IJKLM(5),NW               ST001410
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR,INDIC       ST001420
      COMMON /ADIR/ NA,I(10)                                            ST001430
      COMMON /NAMES/ LOOP(3),NEXT(3),LSKIP(3),LNAME(3)                  ST001440
      COMMON /ERROR/ NERR,MODE,NTIME                                    ST001450
      IF(INDIC)CALL SECOND(T0)                                          ST001460
      INDIC = .FALSE.                                                   ST001470
  100 CALL SECOND(T)                                                    ST001480
      TD=T-T0                                                           ST001490
      IF(NO.EQ.0 .AND. NTIME.EQ.0)WRITE(NWRITE,2000)TD                  ST001500
      T0=T                                                              ST001510
      IF(LA.EQ.0) CALL OPREAD(IERR)                                     ST001520
      IF(LA.EQ.0 .OR. IERR .NE. 1) GO TO 175                            ST001530
      CALL FIND(LNAME,IERR)                                             ST001540
      IF(IERR .NE. 1) RETURN                                            ST001550
  150 CALL OPSTOR(L(NA),NW,IERR)                                        ST001560
      IF(IERR .NE. 1) RETURN                                            ST001570
      IF(LA.EQ.0) GO TO 100                                             ST001580
  175 RETURN                                                            ST001590
 2000 FORMAT(1X,30(1H-),F10.3,8H SECONDS )                              ST001600
      END                                                               ST001610
```

```
      SUBROUTINE OPREAD(IERR)                                           ST001620
      IMPLICIT REAL*8 (A-H,O-Z)                                         ST001630
      COMMON MTOT,NDP,L(1)                                              ST001640
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             ST001650
      COMMON /CARD/ INHOL(3,10),NN(4),S1,S2                             ST001660
      COMMON /LOOPD/ LA,IN,INDEX(5),LSTART(5),IJKLM(5),NW               ST001670
      COMMON /NAMES/ LOOP(3),NEXT(3),LSKIP(3),LNAME(3)                  ST001680
      LOGICAL COMP                                                      ST001690
C-----READ AND PRINT ALL INPUT OPERATION CARDS-----------------         ST001700
      N=NSIZE+NDIR                                                      ST001710
      IN=0                                                              ST001720
  100 CALL RCARD(IERR)                                                  ST001730
      IF(IERR .NE. 1) RETURN                                            ST001740
      IF(COMP(INHOL(1,1),LOOP)) IN=IN+1                                 ST001750
      IF((IN.EQ.1).AND.(LA.EQ.0)) LA=1                                  ST001760
      IF(LA.EQ.0) RETURN                                                ST001770
C-----STORE ALL OPERATIONS WITHIN OUTER LOOP-----------                 ST001780
      DO 200 J=1,10                                                     ST001790
      DO 200 I=1,NH                                                     ST001800
      L(N)=INHOL(I,J)                                                   ST001810
  200 N=N+1                                                             ST001820
      DO 210 I=1,4                                                      ST001830
      L(N)=NN(I)                                                        ST001840
  210 N=N+1                                                             ST001850
      IF(COMP(INHOL(1,1),NEXT)) IN=IN-1                                 ST001860
      IF(IN.EQ.0) GO TO 250                                             ST001870
      LA=LA+1                                                           ST001880
      GO TO 100                                                         ST001890
C     SET NAME AND STORAGE FOR LOOP DATA                                ST001900
  250 CALL LIST(LNAME,NW,LA,NSP,IERR)                                   ST001910
      IF(IERR .NE. 1)RETURN                                             ST001920
  300 LA=1                                                              ST001930
      IN=0                                                              ST001940
      RETURN                                                            ST001950
      END                                                               ST001960
      SUBROUTINE RCARD(IERR)                                            ST001970
C                                                                       ST001980
C-----RCARD READS AND INTERPRETES AN OPERATION                          ST001990
C                                                                       ST002000
      IMPLICIT REAL*8 (A-H,O-Z)                                         ST002010
      COMMON MTOT,NDP,L(1)                                              ST002020
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             ST002030
      COMMON /CARD/ INHOL(3,10),NN(4),S1,S2                             ST002040
      COMMON /RECON/ IN(80),INDIGT(80),ITAB(5,4),NUM(10),LBYTE          ST002050
      DATA IBLANK/2H  /,IALPHA/2HA /,IZULU/2HZ /,ICOMMA/2H, /           ST002060
C-----READ OP,M1,M2,M3,M4,N1,N2,N3,N4                                   ST002070
   10 READ(NREAD,1000)IN                                                ST002080
      IF(NO.EQ.0)WRITE(NWRITE,2000)IN                                   ST002090
 1000 FORMAT(80A1)                                                      ST002100
```

```
 2000 FORMAT(3H **,80A1)                                                  STO02110
C-----SET INITIAL CONDITIONS                                              STO02120
      DO 50 J=1,10                                                        STO02130
      DO 50 I = 1,NH                                                      STO02140
   50 INHOL(I,J) = IBLANK                                                 STO02150
      DO 60 J = 1,4                                                       STO02160
   60 NN(J) = 0                                                           STO02170
      IER = 0                                                             STO02180
      IEND = 80                                                           STO02190
      IROW = 1                                                            STO02200
      J = 1                                                               STO02210
      II = 1                                                              STO02220
      JNUM = 1                                                            STO02230
      IBYTE = 0                                                           STO02240
      JJ = 1                                                              STO02250
C-----IDENTIFY CHARACTER INDEX AND STORE IN INDIGT                        STO02260
      DO 90 K = 1,80                                                      STO02270
      IJ = IN(K)                                                          STO02280
      KTYPE = 400                                                         STO02290
      IF(IJ.EQ.IBLANK)GO TO 100                                           STO02300
      DO 70 I = 1,10                                                      STO02310
      IF(IJ.NE.NUM(I))GO TO 70                                            STO02320
      KTYPE  = 100 + I                                                    STO02330
      GO TO 90                                                            STO02340
   70 CONTINUE                                                            STO02350
      IF(IJ.NE.ICOMMA)GO TO 80                                            STO02360
      KTYPE = 200                                                         STO02370
      GO TO 90                                                            STO02380
   80 IF(IJ.GE.IALPHA .AND. IJ.LE.IZULU)KTYPE = 300                       STO02390
   90 INDIGT(K) = KTYPE                                                   STO02400
      GO TO 120                                                           STO02410
  100 IEND = K - 1                                                        STO02420
C-----INTERPRET CHARACTER AND TRANSFER TO VARIABLE IN CARD COMMON         STO02430
  120 ICOL = INDIGT(J)/100                                                STO02440
      ISTAT = ITAB(IROW,ICOL)                                             STO02450
C-----SEPARATE ACTION DIGIT FROM STATE DIGIT                              STO02460
      IACT = ISTAT/100                                                    STO02470
      IROW = ISTAT - 100*IACT                                             STO02480
      GO TO (200,300,400,500,700),IACT                                    STO02490
C-----HOLLERITH DATA                                                      STO02500
  200 IBYTE = IBYTE + 1                                                   STO02510
      IF(IBYTE.LE.LBYTE)GO TO 210                                         STO02520
      IBYTE = 1                                                           STO02530
      II = II + 1                                                         STO02540
  210 CALL MOVEB(INHOL(II,JJ),IBYTE,IN(J),1)                              STO02550
      GO TO 600                                                           STO02560
C-----NUMERICAL DATA                                                      STO02570
  300 NNN = MOD(INDIGT(J),10)                                             STO02580
      NN(JNUM)=10*NN(JNUM)+NNN                                            STO02590
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      GO TO 600                                                          STO02600
C-----COMMA AFTER HOLLERITH DATA                                         STO02610
  400 JJ=JJ+1                                                            STO02620
      II = 1                                                             STO02630
      IBYTE = 0                                                          STO02640
      IF(JJ.GT.10 .AND. J.LT.IEND .AND. INDIGT(J+1).GT.200)GO TO 700     STO02650
      GO TO 600                                                          STO02660
C-----COMMA AFTER NUMERICAL DATA                                         STO02670
  500 JNUM = JNUM + 1                                                    STO02680
      IF(JNUM.GT.4 .AND. J.LT.IEND)GO TO 700                             STO02690
  600 J = J + 1                                                          STO02700
      IF(J.LE.IEND)GO TO 120                                             STO02710
      GO TO 710                                                          STO02720
  700 WRITE(NWRITE,3000)                                                 STO02730
 3000 FORMAT(29H0  INPUT CARD ERROR, RE-ENTER)                           STO02740
      IERR = 2                                                           STO02750
  710 RETURN                                                             STO02760
      END                                                                STO02770
      SUBROUTINE OPSTOR(LOOPA,NW,IERR)                                   STO02780
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO02790
      LOGICAL COMP                                                       STO02800
      COMMON MTOT,NDP,L(1)                                               STO02810
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR              STO02820
      COMMON /CARD/ INHOL(3,10),NN(4),S1,S2                              STO02830
      COMMON /LOOPD/ LA,IN,INDEX(5),LSTART(5),IJKLM(5)                   STO02840
      COMMON /ADIR/NA,III(10)                                            STO02850
      COMMON /NAMES/ LOOP(3),NEXT(3),LSKIP(3),LNAME(3)                   STO02860
      DIMENSION LOOPA(NW,1)                                              STO02870
      DATA IBLANK/4H    /                                                STO02880
      IF(LA.NE.1) GO TO 50                                               STO02890
      DO 40 I=1,5                                                        STO02900
   40 IJKLM(I)=0                                                         STO02910
      IF(NO.EQ.0) WRITE(NWRITE,2001)                                     STO02920
C-----TRANSFER OPERATION FROM STORAGE TO CARD COMMON   ----------        STO02930
   50 I=1                                                                STO02940
      DO 100 J=1,10                                                      STO02950
      DO 100 K=1,NH                                                      STO02960
      INHOL(K,J)=LOOPA(I,LA)                                             STO02970
  100 I=I+1                                                              STO02980
      DO 110 J=1,4                                                       STO02990
      NN(J)=LOOPA(I,LA)                                                  STO03000
  110 I=I+1                                                              STO03010
      LA=LA+1                                                            STO03020
      IF(NO.EQ.0) WRITE(NWRITE,2000) ((INHOL(I,J),I=1,NH),J=1,10)        STO03030
     1 ,(IJKLM(I),I=1,IN)                                                STO03040
      IF(COMP(INHOL(1,1),LSKIP)) GO TO 200                               STO03050
      IF(COMP(INHOL(1,1),LOOP)) GO TO 300                                STO03060
      IF(COMP(INHOL(1,1),NEXT)) GO TO 400                                STO03070
      RETURN                                                             STO03080
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C-----SKIP OPERATION- CHECK SIGN AND INCREMENT COUNTER------              STO003090
  200 CALL FIND(INHOL(1,2),IERR)                                         STO003100
      IF(IERR .NE. 1)RETURN                                              STO003110
  250 CALL MOVE(L(NA),S1,NDP)                                            STO003120
      IF(NO.EQ.0)WRITE(NWRITE,2002)(INHOL(J,2),J=1,NH),S1,NN(1)          STO003130
      IF(S1.LT.0.0D0) LA=LA+NN(1)                                        STO003140
      GO TO 50                                                           STO003150
C-----LOOP OPERATION- SET INDEX LIMIT FOR LOOP -----------               STO003160
  300 IN=IN+1                                                            STO003170
      INDEX(IN)=NN(1)                                                    STO003180
      IJKLM(IN)=1                                                        STO003190
      LSTART(IN)=LA                                                      STO003200
      GO TO 50                                                           STO003210
C-----NEXT OPERATION- INCREMENT INDEX AND CHECK FOR LAST OPERATION---     STO003220
  400 INDEX(IN)=INDEX(IN)-1                                              STO003230
      IJKLM(IN)=IJKLM(IN)+1                                              STO003240
      IF(NO.EQ.0) WRITE(NWRITE,2003)IN                                   STO003250
      IF(INHOL(1,2).EQ.IBLANK) GO TO 450                                 STO003260
      CALL FIND(INHOL(1,2),IERR)                                         STO003270
      IF(IERR .NE. 1)RETURN                                              STO003280
  410 CALL MOVE(L(NA),S1,NDP)                                            STO003290
      IF(NO.EQ.0)WRITE(NWRITE,2002)(INHOL(I,2),I=1,NH),S1                STO003300
      IF(S1.LT.0.0D0) INDEX(IN)=0                                        STO003310
  450 IF(INDEX(IN).NE.0) LA=LSTART(IN)                                   STO003320
      IF(INDEX(IN).EQ.0) IJKLM(IN)=0                                     STO003330
      IF(INDEX(IN).EQ.0) IN=IN-1                                         STO003340
      IF(IN.EQ.0) GO TO 500                                              STO003350
      GO TO 50                                                           STO003360
C-----DELETE ARRAY OF OPERATIONS WITHIN LOOPS--------                    STO003370
  500 LA=0                                                               STO003380
      CALL DELETE(LNAME)                                                 STO003390
      RETURN                                                             STO003400
 2000 FORMAT(5H  *** 20A4,/,1H ,I5,3H=L1,I5,3H=L2,I5,3H=L3,I5,3H=L4,I5,3STO003410
     1 H=L5)                                                             STO003420
 2001 FORMAT(28H0START OF LOOPING OPERATIONS  )                          STO003430
 2002 FORMAT (1X,2A4,3H = E15.7,17H IF NEGATIVE SKIP   I5)               STO003440
 2003 FORMAT(25H LAST OPERATION IN LOOP L ,I1/1H0)                       STO003450
      END                                                                STO003460
      SUBROUTINE ERCOM(IERR)                                             STO003470
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO003480
      COMMON /LOOPD/ LA                                                  STO003490
      COMMON /ERROR/ NERR,MODE,NTIME                                     STO003500
      WRITE(NERR,2000)                                                   STO003510
      IF(LA .GE. 1)WRITE(NERR,3000)                                      STO003520
      IERR = 2                                                           STO003530
      RETURN                                                             STO003540
 2000 FORMAT (24H0MATRICES NOT COMPATIBLE )                              STO003550
 3000 FORMAT (39H0**WARNING  LOOP OPERATIONS CANCELLED**)                STO003560
      END                                                                STO003570
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      SUBROUTINE MOVE(II,JJ,N)                                          ST003580
      IMPLICIT REAL*8 (A-H,O-Z)                                         ST003590
      DIMENSION II(3),JJ(3)                                             ST003600
      DO 100 I=1,N                                                      ST003610
  100 JJ(I)=II(I)                                                       ST003620
      RETURN                                                            ST003630
      END                                                               ST003640
      FUNCTION COMP(I,J)                                                ST003650
      IMPLICIT REAL*8 (A-H,O-Z)                                         ST003660
      DIMENSION I(3),J(3)                                               ST003670
      LOGICAL COMP                                                      ST003680
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             ST003690
      COMP=.FALSE.                                                      ST003700
      DO 100 K=1,NH                                                     ST003710
      IF(I(K).NE.J(K)) RETURN                                           ST003720
  100 CONTINUE                                                          ST003730
      COMP=.TRUE.                                                       ST003740
      RETURN                                                            ST003750
      END                                                               ST003760
      SUBROUTINE LIST(II,NR,NC,NP,IERR)                                 ST003770
      IMPLICIT REAL*8 (A-H,O-Z)                                         ST003780
      COMMON MTOT,NDP,L(1)                                              ST003790
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             ST003800
      COMMON /ADIR/ NA,I(10)                                            ST003810
      COMMON /ERROR/ NERR,MODE,NTIME                                    ST003820
      DIMENSION II(3),IBLANK(3)                                         ST003830
      LOGICAL COMP                                                      ST003840
      DATA IBLANK/3*4H    /                                             ST003850
      IF(COMP(II,IBLANK)) GO TO 150                                     ST003860
      IF(NR.LT.1 .OR. NC.LT.1)GO TO 150                                 ST003870
      IF(NO.EQ.0) WRITE(NWRITE,2001) NR,NC                              ST003880
      NEL = NR*NC                                                       ST003890
      I(1) = NR*NC                                                      ST003900
      IF(NP.EQ.1 .AND. MOD(NR*NC,NDP).EQ.1) I(1)=NR*NC+1                ST003910
      I(2)=NP                                                           ST003920
      I(3)=NC                                                           ST003930
      I(4)=NR                                                           ST003940
      CALL MOVE(II,I(5),NH)                                             ST003950
C-----CHECK CAPACITY OF L ARRAY                                         ST003960
      NN=I(1)*I(2)+NDIR                                                 ST003970
      IF(NN.LT.MTOT-NSIZE) GO TO 50                                     ST003980
      NX=NSIZE+NN                                                       ST003990
      WRITE(NERR,2000)MTOT,NX                                           ST004000
      IERR = 2                                                          ST004010
  999 RETURN                                                            ST004020
C-----SET DIRECTORY AND RESERVE STORAGE FOR NEW ARRAY------             ST004030
   50 DO 100 N=1,NDIR                                                   ST004040
      IN=NSIZE-1+N                                                      ST004050
  100 L(IN)=I(N)                                                        ST004060
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      NA=NSIZE+NDIR                                                          STO04070
      NARA=NARA+1                                                            STO04080
      NSIZE=NSIZE+NN                                                         STO04090
      RETURN                                                                 STO04100
  150 WRITE(NERR,2002)II                                                     STO04110
      IERR = 2                                                               STO04120
      RETURN                                                                 STO04130
 2000 FORMAT (19HOSTORAGE EXCEEDED-- I5,11H RESERVED-- I5,9H REQUIRED)      STO04140
 2001 FORMAT(I5,6H ROWS ,I5,8H COLUMNS )                                    STO04150
 2002 FORMAT(11HO  MATRIX $,3A4,25H$ ARGUMENT ERROR.  REPEAT )              STO04160
      END                                                                    STO04170
      SUBROUTINE FIND(II,IERR)                                               STO04180
      IMPLICIT REAL*8 (A-H,O-Z)                                              STO04190
      COMMON MTOT,NDP,L(1)                                                   STO04200
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                  STO04210
      COMMON /ADIR/ NA,I(10)                                                 STO04220
      COMMON /ERROR/ NERR,MODE,NTIME                                         STO04230
      DIMENSION II(3)                                                        STO04240
      LOGICAL COMP                                                           STO04250
C-----LOCATE ARRAY AND ITS DIRECTORY-- NA=0 IF ARRAY II IS NOT FOUND         STO04260
      N=1                                                                    STO04270
      NA=0                                                                   STO04280
  100 IF(N.EQ.NSIZE) GO TO 400                                               STO04290
      IF(.NOT.COMP(II,L(N+4))) GO TO 200                                     STO04300
      N=N+L(N)*L(N+1)+NDIR                                                   STO04310
      GO TO 100                                                              STO04320
C-----COMPUTE ADDRESS AND TRANSFER DIRECTORY                                 STO04330
  200 DO 300 K=1,NDIR                                                        STO04340
      M=N+K-1                                                                STO04350
  300 I(K)=L(M)                                                              STO04360
      NA=N+1                                                                 STO04370
      RETURN                                                                 STO04380
  400 WRITE(NERR,2000) (II(J),J=1,NH)                                        STO04390
      IERR = 2                                                               STO04400
  999 RETURN                                                                 STO04410
 2000 FORMAT ( 7HOARRAY$ 2A4,23H$NOT PREVIOUSLY DEFINED )                   STO04420
      END                                                                    STO04430
      SUBROUTINE DELETE(II)                                                  STO04440
      IMPLICIT REAL*8 (A-H,O-Z)                                              STO04450
      COMMON MTOT,NDP,L(1)                                                   STO04460
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                  STO04470
      COMMON /ADIR/ NA,I(10)                                                 STO04480
      DIMENSION II(3)                                                        STO04490
      LOGICAL COMP                                                           STO04500
C-----LOCATE ARRAY TO BE DELETED                                             STO04510
      N=1                                                                    STO04520
      NA=0                                                                   STO04530
   10 IF(N.EQ.NSIZE) RETURN                                                  STO04540
      IF(.NOT.COMP(II,L(N+4))) GO TO 20                                      STO04550
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      N=N+L(N)*L(N+1)+NDIR                                                  STO04560
      GO TO 10                                                              STO04570
C-----COMPUTE ADDRESS AND TRANSFER DIRECTORY                                STO04580
   20 DO 30  K=1,NDIR                                                       STO04590
      M=N+K-1                                                               STO04600
   30 I(K)=L(M)                                                             STO04610
      NA=1+1                                                                STO04620
C-----DELETE ARRAY AND RELOCATE REMAINING ARRAYS                            STO04630
      NARA=NARA-1                                                           STO04640
      NN=NA+I(1)*I(2)                                                       STO04650
      NL=NSIZE-1                                                            STO04660
      NSH=NDIR+I(1)*I(2)                                                    STO04670
      IF(NN.EQ.NSIZE) GO TO 200                                             STO04680
      DO 100 N=NN,NL                                                        STO04690
  100 L(N-NSH)=L(N)                                                         STO04700
  200 NSIZE=NSIZE-NSH                                                       STO04710
      IF(NO.EQ.0) WRITE(NWRITE,2000) (II(J),J=1,NH)                         STO04720
      RETURN                                                                STO04730
 2000 FORMAT (8H -ARRAY$ 2A4,8H$DELETED )                                   STO04740
      END                                                                   STO04750
      SUBROUTINE GROUP1(LAST,IERR)                                          STO04760
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO04770
      COMMON MTOT,NDP,L(1)                                                  STO04780
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO04790
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR,INDIC           STO04800
      COMMON /ERROR/ NERR,MODE,NTIME                                        STO04810
      COMMON /PSAVE/ NUMNP,NEQ,NPROP,NUMEL,NTRUSS,NT,NSAVE                 STO04820
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)                STO04830
      LOGICAL COMP,INDIC                                                    STO04840
      DIMENSION IOP(3,34)                                                   STO04850
      DATA IOP(1,1),IOP(2,1),IOP(3,1) /4HSTAR,4HT   ,4H    /               STO04860
      DATA IOP(1,2),IOP(2,2),IOP(3,2) /4HLOAD,4H    ,4H    /               STO04870
      DATA IOP(1,3),IOP(2,3),IOP(3,3) /4HPRIN,4HT   ,4H    /               STO04880
      DATA IOP(1,4),IOP(2,4),IOP(3,4) /4HZERO,4H    ,4H    /               STO04890
      DATA IOP(1,5),IOP(2,5),IOP(3,5) /4HDELE,4HTE  ,4H    /               STO04900
      DATA IOP(1,6),IOP(2,6),IOP(3,6) /4HDUP ,4H    ,4H    /               STO04910
      DATA IOP(1,7),IOP(2,7),IOP(3,7) /4HADD ,4H    ,4H    /               STO04920
      DATA IOP(1,8),IOP(2,8),IOP(3,8) /4HSUB ,4H    ,4H    /               STO04930
      DATA IOP(1,9),IOP(2,9),IOP(3,9) /4HNO  ,4H    ,4H    /               STO04940
      DATA IOP(1,10),IOP(2,10),IOP(3,10) /4HYES ,4H    ,4H    /           STO04950
      DATA IOP(1,11),IOP(2,11),IOP(3,11) /4HSTOP,4H    ,4H    /           STO04960
      DATA IOP(1,12),IOP(2,12),IOP(3,12) /4HMULT,4H    ,4H    /           STO04970
      DATA IOP(1,13),IOP(2,13),IOP(3,13) /4HTRAN,4H    ,4H    /           STO04980
      DATA IOP(1,14),IOP(2,14),IOP(3,14) /4HINVE,4HL   ,4H    /           STO04990
      DATA IOP(1,15),IOP(2,15),IOP(3,15) /4HSORE,4HL   ,4H    /           STO05000
      DATA IOP(1,16),IOP(2,16),IOP(3,16) /4HDLOG,4H    ,4H    /           STO05010
      DATA IOP(1,17),IOP(2,17),IOP(3,17) /4HSCAL,4HE   ,4H    /           STO05020
      DATA IOP(1,18),IOP(2,18),IOP(3,18) /4HSOLV,4HE   ,4H    /           STO05030
      DATA IOP(1,19),IOP(2,19),IOP(3,19) /4HUSER,4HA   ,4H    /           STO05040
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      DATA IOP(1,20),IOP(2,20),IOP(3,20) /4HUSER,4HB   ,4H    /          ST005050
      DATA IOP(1,21),IOP(2,21),IOP(3,21) /4HMAX ,4H    ,4H    /          ST005060
      DATA IOP(1,22),IOP(2,22),IOP(3,22) /4HNORM,4H    ,4H    /          ST005070
      DATA IOP(1,23),IOP(2,23),IOP(3,23) /4HPROD,4H    ,4H    /          ST005080
      DATA IOP(1,24),IOP(2,24),IOP(3,24) /4HDUPS,4HM   ,4H    /          ST005090
      DATA IOP(1,25),IOP(2,25),IOP(3,25) /4HSTOS,4HM   ,4H    /          ST005100
      DATA IOP(1,26),IOP(2,26),IOP(3,26) /4HDUPD,4HG   ,4H    /          ST005110
      DATA IOP(1,27),IOP(2,27),IOP(3,27) /4HSTOD,4HG   ,4H    /          ST005120
      DATA IOP(1,28),IOP(2,28),IOP(3,28) /4HLABE,4HL   ,4H    /          ST005130
      DATA IOP(1,29),IOP(2,29),IOP(3,29)/4HREAD,4H    ,4H    /          ST005140
      DATA IOP(1,30),IOP(2,30),IOP(3,30) /4HWRIT,4HE   ,4H    /          ST005150
      DATA IOP(1,31),IOP(2,31),IOP(3,31) /4HTIME,4H    ,4H    /          ST005160
      DATA IOP(1,32),IOP(2,32),IOP(3,32) /4HSAVE,4H    ,4H    /          ST005170
      DATA IOP(1,33),IOP(2,33),IOP(3,33) /4HRESU,4HME  ,4H    /          ST005180
      DATA IOP(1,34),IOP(2,34),IOP(3,34) /4HLIST,4H    ,4H    /          ST005190
      NUMOP=34                                                          ST005200
      GO TO 175                                                         ST005210
C---- READ OPERATION FROM CARD OR STORAGE  -----------------            ST005220
  100 IF (IERR .GT. 1) RETURN                                           ST005230
      CALL INPUT(IERR)                                                  ST005240
      IF(IERR .GT. 1) RETURN                                            ST005250
C-----INTERPRETE OPERATION ---------------------------------            ST005260
  175 DO 200 J=1,NUMOP                                                  ST005270
      N=J                                                               ST005280
      IF (COMP(INHOL(1,1),IOP(1,J))) GO TO 300                          ST005290
  200 CONTINUE                                                          ST005300
      RETURN                                                            ST005310
C-----EXECUTE APPROPRIATE OPERATION ----------------------             ST005320
  300 LAST=1                                                            ST005330
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,  ST005340
     1 23,24,25,26,27,28,29,30,31,32,33,34),N                           ST005350
    1 NARG=0                                                            ST005360
      NSIZE=1                                                           ST005370
      NO=0                                                              ST005380
      WRITE(NWRITE,2000)                                                ST005390
      GO TO 100                                                         ST005400
    2 CALL LOAD (IERR)                                                  ST005410
      GO TO 100                                                         ST005420
    3 IF(N1.GT.0) CALL LABEL(N1)                                        ST005430
      IF(NO.EQ.0) CALL PRINT(IERR)                                      ST005440
      GO TO 100                                                         ST005450
    4 CALL ZERO (IERR)                                                  ST005460
      GO TO 100                                                         ST005470
    5 CALL DELETE(INHOL(1,2))                                           ST005480
      GO TO 100                                                         ST005490
    6 CALL DUP  (IERR)                                                  ST005500
      GO TO 100                                                         ST005510
    7 CALL ADD(1.00,IERR)                                               ST005520
      GO TO 100                                                         ST005530
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 8 CALL ADD(-1.D0,IERR)                                                 STO05540
   GO TO 100                                                            STO05550
 9 NO=1                                                                 STO05560
   GO TO 100                                                            STO05570
10 NO=0                                                                 STO05580
   GO TO 100                                                            STO05590
11 IF(NRP.GT.1)END FILE NT                                              STO05600
   STOP                                                                 STO05610
12 CALL MUL  (IERR)                                                     STO05620
   GO TO 100                                                            STO05630
13 CALL TRAN(IERR)                                                      STO05640
   GO TO 100                                                            STO05650
14 CALL MOP(1,IERR)                                                     STO05660
   GO TO 100                                                            STO05670
15 CALL MOP(2,IERR)                                                     STO05680
   GO TO 100                                                            STO05690
16 CALL MOP(3,IERR)                                                     STO05700
   GO TO 100                                                            STO05710
17 CALL MOP(4,IERR)                                                     STO05720
   GO TO 100                                                            STO05730
18 CALL SYMSV(IERR)                                                     STO05740
   GO TO 100                                                            STO05750
19 CALL USERA(IERR)                                                     STO05760
   GO TO 100                                                            STO05770
20 CALL USERB(IERR)                                                     STO05780
   GO TO 100                                                            STO05790
21 CALL MOP(5,IERR)                                                     STO05800
   GO TO 100                                                            STO05810
22 CALL MOP(6,IERR)                                                     STO05820
   GO TO 100                                                            STO05830
23 CALL MOP(7,IERR)                                                     STO05840
   GO TO 100                                                            STO05850
24 CALL SMOP(1,IERR)                                                    STO05860
   GO TO 100                                                            STO05870
25 CALL SMOP(2,IERR)                                                    STO05880
   GO TO 100                                                            STO05890
26 CALL DGOP(1,IERR)                                                    STO05900
   GO TO 100                                                            STO05910
27 CALL DGOP(2,IERR)                                                    STO05920
   GO TO 100                                                            STO05930
28 IF(N1.GT.0) CALL LABEL(N1)                                           STO05940
   GO TO 100                                                            STO05950
29 IF(MODE .NE. 1) NREAD=N1                                             STO05960
   IF(MODE .EQ. 1) WRITE(NERR,2001)                                     STO05970
   GO TO 100                                                            STO05980
30 IF(MODE .NE. 1) NWRITE=N1                                            STO05990
   IF(MODE .EQ. 1) WRITE(NERR,2001)                                     STO06000
   GO TO 100                                                            STO06010
31 NTIME = 1 - NTIME                                                    STO06020
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      GO TO 100                                                          STO06030
   32 CALL SAVE (NARA,NSIZE,L,MTOT,1)                                    STO06040
      WRITE (NWRITE,2005)NARA,NSIZE,MTOT                                 STO06050
      J=1                                                                STO06060
      GO TO 400                                                          STO06070
   33 CALL SAVE(NARA,NSIZE,L,MTOT,2)                                     STO06080
   34 J=1                                                                STO06090
      WRITE(NWRITE,2003)NARA,NSIZE,MTOT                                  STO06100
  400 IF(J.EQ.NSIZE)GO TO 100                                            STO06110
      K=J+4                                                              STO06120
      KJ=J+NH+3                                                          STO06130
      WRITE(NWRITE,2004)(L(KK),KK=K,KJ),L(J+3),L(J+2)                    STO06140
      J=J+L(J)*L(J+1)+NDIR                                               STO06150
      GO TO 400                                                          STO06160
 2000 FORMAT (1H1)                                                       STO06170
 2001 FORMAT (22H0 COMMAND NOT EXECUTED)                                 STO06180
 2003 FORMAT(11H0 THERE ARE,I4,19H ARRAYS IN STORAGE.,I7,                 STO06190
     1 36H STORAGE POSITIONS HAVE BEEN USED OF,I7,10H RESERVED.)         STO06200
 2004 FORMAT (8H ARRAY #,2A4,5H# HAS,I6,9H ROWS AND,I6,9H COLUMNS.)      STO06210
 2005 FORMAT (1H0,I4,47H ARRAYS HAVE BEEN SAVED.  THESE ARRAYS OCCUPIED,STO06220
     1 I7,25H STORAGE POSITIONS OF THE,I7,20H POSITIONS RESERVED.)       STO06230
      END                                                                STO06240
      SUBROUTINE SAVE(I,J,K,L,M)                                         STO06250
      COMMON /PSAVE/ NUMNP,NEQ,NPROP,NUMEL,NTRUSS,NT,NSAVE               STO06260
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)             STO06270
      DIMENSION K(L)                                                     STO06280
      REWIND NSAVE                                                       STO06290
      GO TO (1,2),M                                                      STO06300
    1 WRITE (NSAVE) I,J,NUMNP,NEQ,NPROP,NUMEL,NTRUSS,NRP,K               STO06310
      END FILE NSAVE                                                     STO06320
      RETURN                                                             STO06330
    2 READ (NSAVE) I,J,NUMNP,NEQ,NPROP,NUMEL,NTRUSS,NRP,K               STO06340
      RETURN                                                             STO06350
      END                                                                STO06360
      SUBROUTINE LOAD(IERR)                                              STO06370
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO06380
      COMMON MTOT,NDP,L(1)                                               STO06390
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR              STO06400
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                        STO06410
      COMMON /ADIR/ NA,I(10)                                             STO06420
      CALL DELETE(INHOL(1,2))                                            STO06430
      CALL LIST(INHOL(1,2),N1,N2,NDP,IERR)                               STO06440
      IF(IERR .GT. 1) RETURN                                             STO06450
  100 CALL RLOAD(L(NA),N1,N2,N3)                                         STO06460
  999 RETURN                                                             STO06470
      END                                                                STO06480
      SUBROUTINE RLOAD(A,NR,NC,N3)                                       STO06490
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO06500
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR              STO06510
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      COMMON /TEMP/ FOR(40)                                                 STO06520
      DIMENSION A(NR,1)                                                     STO06530
      IF(N3.NE.0) GO TO 100                                                 STO06540
      READ(NREAD,1000)((A(I,J),J=1,NC),I=1,NR)                              STO06550
      RETURN                                                                STO06560
  100 READ(NREAD,1001)FOR                                                   STO06570
      READ(NREAD,FOR)((A(I,J),J=1,NC),I=1,NR)                               STO06580
      RETURN                                                                STO06590
 1000 FORMAT (8F10.0)                                                       STO06600
 1001 FORMAT(40A2)                                                          STO06610
      END                                                                   STO06620
      SUBROUTINE PRINT(IERR)                                                STO06630
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO06640
      COMMON MTOT,NDP,L(1)                                                  STO06650
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO06660
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO06670
      COMMON /ADIR/ NA,I(10)                                                STO06680
      CALL FIND(INHOL(1,2),IERR)                                            STO06690
      IF(IERR .GT. 1) RETURN                                                STO06700
  100 NR=I(4)                                                               STO06710
      CALL RPRT(L(NA),NR,I(3),N2)                                           STO06720
  999 RETURN                                                                STO06730
      END                                                                   STO06740
      SUBROUTINE RPRT(A,NR,NC,N2)                                           STO06750
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO06760
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO06770
      DIMENSION A(NR,1)                                                     STO06780
      IF(N2.LT.1 .OR. N2.GT.8)N2=8                                          STO06790
      DO 100  I=1,NC,N2                                                     STO06800
      WRITE(NWRITE,2002)                                                    STO06810
      IH = MINO(I+N2-1,NC)                                                  STO06820
      WRITE(NWRITE,2000)  (K,K=I,IH)                                        STO06830
      DO 100 J=1,NR                                                         STO06840
  100 WRITE(NWRITE,2001)  (J,(A(J,K),K=I,IH))                               STO06850
      RETURN                                                                STO06860
 2000 FORMAT (1H ,5X,8(I8,7X))                                              STO06870
 2001 FORMAT (1H ,I5,8(1PD15.7))                                            STO06880
 2002 FORMAT (1H0)                                                          STO06890
      END                                                                   STO06900
      SUBROUTINE LABEL(N1)                                                  STO06910
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO06920
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO06930
      COMMON /TEMP/ II(40)                                                  STO06940
      DO 100 I=1,N1                                                         STO06950
      READ(NREAD,1000)II                                                    STO06960
      IF(NO.EQ.0)  WRITE(NWRITE,1000)  II                                   STO06970
  100 CONTINUE                                                              STO06980
      RETURN                                                                STO06990
 1000 FORMAT (40A2)                                                         STO07000
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      END                                                                   STO07010
      SUBROUTINE ZERO(IERR)                                                 STO07020
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO07030
      COMMON MTOT,NDP,L(1)                                                  STO07040
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO07050
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO07060
      COMMON /ADIR/ NA,I(10)                                                STO07070
      S1=N3                                                                 STO07080
      S2=N4                                                                 STO07090
      CALL DELETE(INHOL(1,2))                                               STO07100
      CALL LIST(INHOL(1,2),N1,N2,NDP,IERR)                                  STO07110
      IF(IERR .GT. 1) RETURN                                                STO07120
  100 CALL ZEROS(L(NA))                                                     STO07130
  999 RETURN                                                                STO07140
      END                                                                   STO07150
      SUBROUTINE ZEROS(A)                                                   STO07160
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO07170
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO07180
      DIMENSION A(1)                                                        STO07190
      NEL=N1*N2                                                             STO07200
      DO 100 II = 1,NEL                                                     STO07210
  100 A(II) = S2                                                            STO07220
      L=1                                                                   STO07230
      NN = MINO (N1,N2)                                                     STO07240
      DO 200 JJ = 1,NN                                                      STO07250
      A(L) = S1                                                             STO07260
  200 L = L + N1 + 1                                                        STO07270
      RETURN                                                                STO07280
      END                                                                   STO07290
      SUBROUTINE DUP(IERR)                                                  STO07300
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO07310
      COMMON MTOT,NDP,L(1)                                                  STO07320
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO07330
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO07340
      COMMON /ADIR/ NA,I(10)                                                STO07350
      CALL DELETE(INHOL(1,3))                                               STO07360
      CALL FIND (INHOL(1,2),IERR)                                           STO07370
      IF(IERR .GT. 1) RETURN                                                STO07380
  100 NR=I(4)                                                               STO07390
      NC=I(3)                                                               STO07400
      NB=NA                                                                 STO07410
      CALL LIST(INHOL(1,3),NR,NC,NDP,IERR)                                  STO07420
      IF(IERR .GT. 1) RETURN                                                STO07430
      NEL = NR*NC                                                           STO07440
  200 CALL DUPL(L(NB),L(NA),NEL)                                            STO07450
  999 RETURN                                                                STO07460
      END                                                                   STO07470
      SUBROUTINE DUPL(A,B,NEL)                                              STO07480
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO07490
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      DIMENSION A(1),B(1)                                                   STO07500
      DO 100 I=1,NEL                                                        STO07510
  100 B(I)=A(I)                                                             STO07520
      RETURN                                                                STO07530
      END                                                                   STO07540
      SUBROUTINE DGOP(N,IERR)                                               STO07550
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO07560
      COMMON MTOT,NDP,L(1)                                                  STO07570
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO07580
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO07590
      COMMON /ADIR/ NA,I(10)                                                STO07600
C-----SUBROUTINE TO DUPLICATE OR STORE DIAGONAL-------------                STO07610
      IF(N.EQ.1) CALL DELETE(INHOL(1,3))                                    STO07620
      CALL FIND(INHOL(1,2),IERR)                                            STO07630
      IF(IERR .GT. 1) RETURN                                                STO07640
   10 N1=I(3)                                                               STO07650
      IF(I(3).NE.I(4)) CALL ERCOM(IERR)                                     STO07660
      IF(IERR .GT. 1) RETURN                                                STO07670
   20 N2=NA                                                                 STO07680
      IF(N.NE.1) GO TO 100                                                  STO07690
      CALL LIST(INHOL(1,3),1,N1,NDP,IERR)                                   STO07700
      IF(IERR .GT. 1) RETURN                                                STO07710
  100 CALL FIND(INHOL(1,3),IERR)                                            STO07720
      IF(IERR .GT. 1) RETURN                                                STO07730
  110 N5=I(3)*I(4)                                                          STO07740
      IF(N5.NE.N1) CALL ERCOM(IERR)                                         STO07750
      IF(IERR .GT. 1) RETURN                                                STO07760
  200 N3=NA                                                                 STO07770
      CALL DGOPS(L(N2),L(N3),N1,N)                                          STO07780
  999 RETURN                                                                STO07790
      END                                                                   STO07800
      SUBROUTINE DGOPS(A,B,M,N)                                             STO07810
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO07820
      DIMENSION A(1),B(1)                                                   STO07830
      DO 300 I=1,M                                                          STO07840
      IA = M*(I-1) + I                                                      STO07850
      GO TO (1,2),N                                                         STO07860
    1 B(I)=A(IA)                                                            STO07870
      GO TO 300                                                             STO07880
    2 A(IA)=B(I)                                                            STO07890
  300 CONTINUE                                                              STO07900
      RETURN                                                                STO07910
      END                                                                   STO07920
      SUBROUTINE MOP(N,IERR)                                                STO07930
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO07940
      COMMON MTOT,NDP,L(1)                                                  STO07950
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO07960
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO07970
      COMMON /ADIR/ NA,I(10)                                                STO07980
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      IF(N.GT.4)  CALL DELETE(INHOL(1,3))                                STO07990
      CALL FIND(INHOL(1,2),IERR)                                         STO08000
      IF(IERR .GT. 1) RETURN                                             STO08010
  100 N3=NA                                                              STO08020
      NC=L(3)                                                            STO08030
      NR=L(4)                                                            STO08040
      IF(N.EQ.4)CALL FIND(INHOL(1,3),IERR)                               STO08050
      IF(N.EQ.5)  CALL LIST(INHOL(1,3),NR,1,NDP,IERR)                    STO08060
      IF(N.EQ.6)  CALL LIST(INHOL(1,3),1,NC,NDP,IERR)                    STO08070
      IF(N.EQ.7)  CALL LIST(INHOL(1,3),1,2 ,NDP,IERR)                    STO08080
      IF(IERR .GT. 1)RETURN                                              STO08090
      CAL. MOPS(L(N3),L(NA),NR,NC,N,N1)                                  STO08100
  999 RETURN                                                             STO08110
      END                                                                STO08120
      SUBROUTINE MOPS(A,B,NR,NC,N,N1)                                    STO08130
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO08140
      COMMON MTOT,NDP,L(1)                                               STO08150
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR              STO08160
      DIMENSION A(1),B(1)                                                STO08170
      NEL = NR*NC                                                        STO08180
      GO TO (100,200,300,400,500,600,700),N                              STO08190
C-----REPLACE EACH ELEMENT WITH ITS INVERSE------                        STO08200
  100 DO 150 I=1,NEL                                                     STO08210
  150 A(I)=1.0D0/A(I)                                                    STO08220
      RETURN                                                             STO08230
C-----REPLACE EACH ELEMENT WITH ITS SQUARE ROOT---                       STO08240
  200 DO 250 I=1,NEL                                                     STO08250
  250 A(I)=DSQRT(A(I))                                                   STO08260
      RETURN                                                             STO08270
C-----REPLACE EACH ELEMENT WITH ITS LOG-----------                       STO08280
  300 DO 350 I=1,NEL                                                     STO08290
  350 A(I)=DLOG(A(I))                                                    STO08300
      RETURN                                                             STO08310
C-----REPLACE EACH ELEMENT WITH ITS SELF TIMES A SCALAR                  STO08320
  400 DO 450 I=1,NEL                                                     STO08330
  450 A(I)=A(I)*B(1)                                                     STO08340
      RETURN                                                             STO08350
C-----EVALUATE THE MAXIMUM OF EACH ROW------------                       STO08360
  500 DO 550 I=1,NR                                                      STO08370
      B(I)=0.0D0                                                         STO08380
      DO 540 J=1,NC                                                      STO08390
      IA = NR*(J-1) + I                                                  STO08400
      X=DABS(A(IA))                                                      STO08410
      IF(X.LT.B(I)) GO TO 540                                            STO08420
      B(I)=X                                                             STO08430
      JMAX=J                                                             STO08440
  540 CONTINUE                                                           STO08450
      IF(NO.EQ.0) WRITE(NWRITE,2000) JMAX,B(I)                           STO08460
 2000 FORMAT (I8,1PD16.7)                                                STO08470
```

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  550 CONTINUE                                                          STO08480
      RETURN                                                            STO08490
C-----EVALUATE COLUMN NORMS-----------------------                      STO08500
  600 DO 650 J=1,NC                                                     STO08510
      B(J)=0.0D0                                                        STO08520
      DO 640 I=1,NR                                                     STO08530
      IA = NR*(J-1) + I                                                 STO08540
      IF(N1.GT.0) GO TO 630                                             STO08550
      B(J)=B(J)+DABS(A(IA))                                             STO08560
      GO TO 640                                                         STO08570
  630 B(J)=B(J)+A(IA)*A(IA)                                             STO08580
  640 CONTINUE                                                          STO08590
      IF(N1.GT.0) B(J)=DSQRT(B(J))                                      STO08600
  650 CONTINUE                                                          STO08610
      RETURN                                                            STO08620
C------EVALUATE PRODUCT OF ALL ELEMENTS-----------                      STO08630
  700 B(1)=1.0D0                                                        STO08640
      B(2)=1.0D0                                                        STO08650
      DO 750 I=1,NR                                                     STO08660
      DO 740 J=1,NC                                                     STO08670
      IA = NR*(J-1) + I                                                 STO08680
      B(1)=B(1)*A(IA)                                                   STO08690
      IF(B(1).NE.0.D0) GO TO 710                                        STO08700
      B(2) = 0.0D0                                                      STO08710
      RETURN                                                            STO08720
  710 IF(DABS(B(1)).LT.1.D0) GO TO 720                                  STO08730
      B(1)=B(1)/10.D0                                                   STO08740
      B(2)=B(2)+1.0D0                                                   STO08750
      GO TO 710                                                         STO08760
  720 IF(DABS(B(1)).GT.0.1D0) GO TO 740                                 STO08770
      B(1)=B(1)*10.D0                                                   STO08780
      B(2)=B(2)-1.0D0                                                   STO08790
      GO TO 720                                                         STO08800
  740 CONTINUE                                                          STO08810
  750 CONTINUE                                                          STO08820
      RETURN                                                            STO08830
      END                                                               STO08840
      SUBROUTINE ADD(S,IERR)                                            STO08850
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO08860
      COMMON MTOT,NDP,L(1)                                              STO08870
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO08880
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                       STO08890
      COMMON /ADIR/ NA,I(10)                                            STO08900
      CALL FIND(INHOL(1,3),IERR)                                        STO08910
      IF(IERR .GT. 1) RETURN                                            STO08920
      NR=I(3)                                                           STO08930
      NEL=I(3)*I(4)                                                     STO08940
      NB=NA                                                             STO08950
      CALL FIND(INHOL(1,2),IERR)                                        STO08960
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      IF(NR.NE.I(3)) CALL ERCOM(IERR)                                   STO08970
      IF(IERR .GT. 1) RETURN                                            STO08980
      CALL ADSB(L(NA),L(NB),NEL,S)                                      STO08990
      RETURN                                                            STO09000
      END                                                               STO09010
      SUBROUTINE ADSB(A,B,NEL,S)                                        STO09020
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO09030
      DIMENSION A(1),B(1)                                               STO09040
      DO 100 IA=1,NEL                                                   STO09050
  100 A(IA)=A(IA)+S*B(IA)                                               STO09060
      RETURN                                                            STO09070
      END                                                               STO09080
      SUBROUTINE MUL(IERR)                                              STO09090
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO09100
      COMMON MTOT,NDP,L(1)                                              STO09110
      COMMON /PSIZE/ NO,NABA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO09120
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                       STO09130
      COMMON /ADIR/ NA,I(10)                                            STO09140
      CALL DELETE(INHOL(1,4))                                           STO09150
      CALL FIND(INHOL(1,2),IERR)                                        STO09160
      IF(IERR .GT. 1) RETURN                                            STO09170
      NR=I(4)                                                           STO09180
      NT=I(3)                                                           STO09190
      N1=NA                                                             STO09200
      CALL FIND(INHOL(1,3),IERR)                                        STO09210
      IF(NT.NE.I(4)) CALL ERCOM(IERR)                                   STO09220
      IF(IERR .GT. 1) RETURN                                            STO09230
      N2=NA                                                             STO09240
      NC=I(3)                                                           STO09250
      CALL LIST(INHOL(1,4),NR,NC,NDP,IERR)                              STO09260
      IF(IERR .GT. 1) RETURN                                            STO09270
      CALL MULT(L(N1),L(N2),L(NA),NR,NT,NC)                             STO09280
      RETURN                                                            STO09290
      END                                                               STO09300
      SUBROUTINE MULT(A,B,C,NRA,NCA,NCB)                                STO09310
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO09320
      DIMENSION A(1),B(1),C(1)                                          STO09330
C-----DIMENSION A(NRA,NCA),B(NCA,NCB),C(NRA,NCB)                        STO09340
      DO 200 I=1,NRA                                                    STO09350
      DO 200 J=1,NCB                                                    STO09360
      X=0.0D0                                                           STO09370
      IC = (J-1)*NRA + I                                                STO09380
      DO 100 K=1,NCA                                                    STO09390
      IA = (K-1)*NRA+I                                                  STO09400
      IB = (J-1)*NCA+K                                                  STO09410
  100 X=X+A(IA)*B(IB)                                                   STO09420
  200 C(IC)=X                                                           STO09430
      RETURN                                                            STO09440
      END                                                               STO09450
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      SUBROUTINE TRAN(IERR)                                                 STO09460
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO09470
      COMMON MTOT,NDP,L(1)                                                  STO09480
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO09490
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO09500
      COMMON /ADIR/ NA,I(10)                                                STO09510
      CALL DELETE(INHOL(1,3))                                               STO09520
      CALL FIND(INHOL(1,2),IERR)                                            STO09530
      IF(IERR .GT. 1) RETURN                                                STO09540
      NR=I(4)                                                               STO09550
      NC=I(3)                                                               STO09560
      N1=NA                                                                 STO09570
      CALL LIST(INHOL(1,3),NC,NR,NDP,IERR)                                  STO09580
      IF(IERR .GT. 1) RETURN                                                STO09590
      CALL TRANS(L(N1),L(NA),NR,NC)                                         STO09600
      RETURN                                                                STO09610
      END                                                                   STO09620
      SUBROUTINE TRANS(A,B,NR,NC)                                           STO09630
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO09640
      DIMENSION A(1),B(1)                                                   STO09650
      K = 1                                                                 STO09660
      DO 100 I = 1,NR                                                       STO09670
      L = I                                                                 STO09680
      DO 100 J = 1,NC                                                       STO09690
      B(K) = A(L)                                                           STO09700
      L = L + NR                                                            STO09710
  100 K = K + 1                                                             STO09720
      RETURN                                                                STO09730
      END                                                                   STO09740
      SUBROUTINE SMOP(N,IERR)                                               STO09750
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO09760
      COMMON MTOT,NDP,L(1)                                                  STO09770
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO09780
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO09790
      COMMON /ADIR/ NA,I(10)                                                STO09800
C-----SUBROUTINE TO DUPLICATE OR STORE SUBMATRICES--------                  STO09810
      IF(N.NE.1) GO TO 100                                                  STO09820
      CALL DELETE(INHOL(1,3))                                               STO09830
      CALL LIST(INHOL(1,3),N3,N4,NDP,IERR)                                  STO09840
      IF(IERR .GT. 1) RETURN                                                STO09850
      GO TO 200                                                             STO09860
  100 CALL FIND(INHOL(1,3),IERR)                                            STO09870
      IF(IERR .GT. 1) RETURN                                                STO09880
      N3=I(4)                                                               STO09890
      N4=I(3)                                                               STO09900
  200 NB=NA                                                                 STO09910
      CALL FIND(INHOL(1,2),IERR)                                            STO09920
      IF(IERR .GT. 1) RETURN                                                STO09930
      NR=I(4)                                                               STO09940
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      NC=I(3)                                                           STO09950
      IF(N1+N3-1.GT.NR) CALL ERCOM(IERR)                                STO09960
      IF(N2+N4-1.GT.NC) CALL ERCOM(IERR)                                STO09970
      IF(IERR .GT. 1) RETURN                                            STO09980
      CALL SMOPS(L(NA),L(NB),NR,NC,N1,N2,N3,N4,N)                       STO09990
      RETURN                                                            STO10000
      END                                                               STO10010
      SUBROUTINE SMOPS(A,B,NR,NC,N1,N2,N3,N4,N)                         STO10020
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO10030
      DIMENSION A(NR,1),B(N3,1)                                         STO10040
      II=N1                                                             STO10050
      DO 400 I=1,N3                                                     STO10060
      JJ=N2                                                             STO10070
      DO 300  J=1,N4                                                    STO10080
      GO TO (1,2),N                                                     STO10090
    1 B(I,J)=A(II,JJ)                                                   STO10100
      GO TO 300                                                         STO10110
    2 A(II,JJ)=B(I,J)                                                   STO10120
  300 JJ=JJ+1                                                           STO10130
  400 II=II+1                                                           STO10140
      RETURN                                                            STO10150
      END                                                               STO10160
      SUBROUTINE SYMSV(IERR)                                            STO10170
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO10180
      COMMON MTOT,NDP,L(1)                                              STO10190
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO10200
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                       STO10210
      COMMON /ADIR/ NA,I(10)                                            STO10220
      IF(NO.NE.0) GO TO 100                                             STO10230
      IF(N1.EQ.1) WRITE(NWRITE,2000)                                    STO10240
      IF (N1.EQ.2) WRITE(NWRITE,2001)                                   STO10250
      IF(N1.EQ.3) WRITE(NWRITE,2002)                                    STO10260
  100 CALL FIND(INHOL(1,2),IERR)                                        STO10270
      IF(IERR .GT. 1) RETURN                                            STO10280
      NR=I(4)                                                           STO10290
      IF(N1.EQ.3) GO TO 300                                             STO10300
      IF(NR.NE.I(3)) CALL ERCOM(IERR)                                   STO10310
      IF(IERR .GT. 1) RETURN                                            STO10320
      N3=NA                                                             STO10330
      IF(N1.EQ.1) GO TO 200                                             STO10340
      CALL FIND(INHOL(1,3),IERR)                                        STO10350
      IF(NR.NE.I(4)) CALL ERCOM(IERR)                                   STO10360
      IF(IERR .GT. 1) RETURN                                            STO10370
  200 CALL SYMSOL(L(N3),L(NA),NR,I(3),N1,N2)                            STO10380
      RETURN                                                            STO10390
  300 CALL SYMIN(L(NA),NR)                                              STO10400
      IF(N2.NE.0)WRITE(NWRITE,2003)                                     STO10410
      RETURN                                                            STO10420
 2000 FORMAT (20H TRIANGULARIZE ONLY  )                                 STO10430
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 2001 FORMAT (44H FORWARD REDUCTION AND BACKSUBSTITUTION ONLY )          STO10440
 2002 FORMAT (22H MATRIX INVERSION ONLY )                               STO10450
 2003 FORMAT(48H0  ***WARNING*** MATRIX REQUIRED TO BE SYMMETRIC)       STO10460
      END                                                               STO10470
      SUBROUTINE SYMSOL(A,B,NN,LL,M,N2)                                 STO10480
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO10490
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO10500
C     SYMMETRIC EQUATION SOLVER- E.L. WILSON 1976                       STO10510
C     M=0 TRIANGULARIZE AND SOLVE                                       STO10520
C     M=1 TRIANGULARIZE ONLY                                            STO10530
C     M=2 FORWARD REDUCTION AND BACKSUBSTITUTION ONLY                   STO10540
C     IF N2 .NE. 0 MATRIX IS NON SYMMETRIC AND LU DECOMPOSITION IS USED.STO10550
      DIMENSION A(NN,1),B(NN,1)                                         STO10560
C     ESTIMATE THE ROUNDOFF VALUE OF ZERO                               STO10570
      ZERO = 0.0D0                                                      STO10580
      DO 10 I = 1,NN                                                    STO10590
   10 ZERO = ZERO + DABS(A(I,I))                                        STO10600
      ZERO = ZERO * 1.0D-16                                             STO10610
      IF(N2.NE.0)GO TO 1000                                             STO10620
C                                                                       STO10630
      IF(M.EQ.2) GO TO 500                                              STO10640
      DO 400 N=1,NN                                                     STO10650
      IF(N.EQ.NN) GO TO 500                                             STO10660
      D=A(N,N)                                                          STO10670
      IF(DABS(D).LT.ZERO) WRITE(NWRITE,2000)N                           STO10680
      N1=N+1                                                            STO10690
      DO 300 J=N1,NN                                                    STO10700
      IF(A(N,J).EQ.0.0D0) GO TO 300                                     STO10710
      A(N,J)=A(N,J)/D                                                   STO10720
      DO 200 I=J,NN                                                     STO10730
      A(I,J)=A(I,J)-A(I,N)*A(N,J)                                       STO10740
  200 A(J,I)=A(I,J)                                                     STO10750
  300 CONTINUE                                                          STO10760
  400 CONTINUE                                                          STO10770
C     FORWARD REDUCTION AND BACKSUBSTITUTION                            STO10780
  500 IF(M.EQ.1) RETURN                                                 STO10790
      DO 700 N=1,NN                                                     STO10800
      DO 600 L=1,LL                                                     STO10810
  600 B(N,L)=B(N,L)/A(N,N)                                              STO10820
      IF(N.EQ.NN) GO TO 800                                             STO10830
      N1=N+1                                                            STO10840
      DO 700 L=1,LL                                                     STO10850
      DO 700 I=N1,NN                                                    STO10860
  700 B(I,L)=B(I,L)-A(I,N)*B(N,L)                                       STO10870
C                                                                       STO10880
  800 N1=N                                                              STO10890
      N=N-1                                                             STO10900
      IF(N.EQ.0) RETURN                                                 STO10910
      DO 900 L=1,LL                                                     STO10920
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      DO 900 J=N1,NN                                                    STO10930
  900 B(N,L)=B(N,L)-A(N,J)*B(J,L)                                       STO10940
      GO TO 800                                                         STO10950
C     NON-SYMMETRIC MATRIX LU DECOMPOSITION                             STO10960
 1000 NM1=NN-1                                                          STO10970
      IF(M.EQ.2)GO TO 1500                                              STO10980
      DO 1100 K=1,NM1                                                   STO10990
      KP1=K+1                                                           STO11000
      AKK=A(K,K)                                                        STO11010
      IF(DABS(AKK).LT.ZERO) WRITE(NWRITE,2000) K                        STO11020
      DO 1100 I=KP1,NN                                                  STO11030
      G=-A(I,K)/AKK                                                     STO11040
      A(I,K) = G                                                        STO11050
      DO 1100 J=KP1,NN                                                  STO11060
 1100 A(I,J)=A(I,J)+G*A(K,J)                                            STO11070
C     FORWARD REDUCTION AND BACK SUBSTITUTION                           STO11080
      IF(M.EQ.1)  RETURN                                                STO11090
 1500 NP1 = NN + 1                                                      STO11100
      DO 1400 L = 1,LL                                                  STO11110
      DO 1200 K = 1,NM1                                                 STO11120
      KP1 = K + 1                                                       STO11130
      BK = B(K,L)                                                       STO11140
      DO 1200 I = KP1,NN                                                STO11150
 1200 B(I,L) = B(I,L) + A(I,K)*BK                                       STO11160
      B(NN,L)=B(NN,L)/A(NN,NN)                                          STO11170
      DO 1400 K = 2,NN                                                  STO11180
      I = NP1-K                                                         STO11190
      J1 = I + 1                                                        STO11200
      BI = B(I,L)                                                       STO11210
      DO 1300 J = J1,NN                                                 STO11220
 1300 BI = BI - A(I,J)*B(J,L)                                           STO11230
      B(I,L)=BI                                                         STO11240
 1400 B(I,L)=B(I,L)/A(I,I)                                              STO11250
      RETURN                                                            STO11260
C                                                                       STO11270
 2000 FORMAT (39H0***ZERO DIAGONAL TERM EQUATION NUMBER   I4)           STO11280
      END                                                               STO11290
      SUBROUTINE SYMIN(A,M)                                             STO11300
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO11310
C-----INVERSION OF POSITIVE DEFINITE SYMMETRIC MATRIX-------           STO11320
      DIMENSION A(M,1)                                                  STO11330
C     EVALUATION OF NEGATIVE INVERSE                                    STO11340
      DO 400 N=1,M                                                      STO11350
      D=A(N,N)                                                          STO11360
      DO 300 I=1,M                                                      STO11370
      AN=A(I,N)/D                                                       STO11380
      IF(I.EQ.N) GO TO 200                                              STO11390
      DO 100 J=I,M                                                      STO11400
      A(I,J)=A(I,J)-AN*A(N,J)                                           STO11410
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  100 A(J,I)=A(I,J)                                                     STO11420
  200 A(I,N)=AN                                                         STO11430
  300 A(N,I)=AN                                                         STO11440
  400 A(N,N)=-1.0D0/D                                                   STO11450
C     CHANGE SIGN OF INVERSE                                          STO11460
      DO 500 I=1,M                                                    STO11470
      DO 500 J=1,M                                                    STO11480
  500 A(I,J)=-A(I,J)                                                  STO11490
C                                                                     STO11500
      RETURN                                                          STO11510
      END                                                             STO11520
      SUBROUTINE USERA(IERR)                                          STO11530
      IMPLICIT REAL*8 (A-H,O-Z)                                       STO11540
      WRITE(NWRITE,1000)                                              STO11550
 1000 FORMAT(37H0 SUBROUTINE USERA IS NOT YET WRITTEN)                STO11560
      RETURN                                                          STO11570
      END                                                             STO11580
      SUBROUTINE USERB (IERR)                                         STO11590
      IMPLICIT REAL*8 (A-H,O-Z)                                       STO11600
      WRITE(NWRITE,1000)                                              STO11610
 1000 FORMAT(37H0 SUBROUTINE USERB IS NOT YET WRITTEN)                STO11620
      RETURN                                                          STO11630
      END                                                             STO11640
      SUBROUTINE GROUP2(LAST,IERR)                                    STO11650
      IMPLICIT REAL*8 (A-H,O-Z)                                       STO11660
      COMMON MTOT,NDP,L(1)                                            STO11670
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR           STO11680
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                     STO11690
      COMMON /TEMP/ SSS(100)                                          STO11700
      LOGICAL COMP                                                    STO11710
      DIMENSION IOP(3,14)                                             STO11720
      DATA IOP(1,1),IOP(2,1),IOP(3,1) /4HNODE,4HS   ,4H   /           STO11730
      DATA IOP(1,2),IOP(2,2),IOP(3,2) /4HBOUN,4HD   ,4H   /           STO11740
      DATA IOP(1,3),IOP(2,3),IOP(3,3) /4HTRUS,4HS   ,4H   /           STO11750
      DATA IOP(1,4),IOP(2,4),IOP(3,4) /4HBEAM,4H    ,4H   /           STO11760
      DATA IOP(1,5),IOP(2,5),IOP(3,5) /4HADDS,4HP   ,4H   /           STO11770
      DATA IOP(1,6),IOP(2,6),IOP(3,6) /4HLOAD,4HS   ,4H   /           STO11780
      DATA IOP(1,7),IOP(2,7),IOP(3,7) /4HFORC,4HE   ,4H   /           STO11790
      DATA IOP(1,8),IOP(2,8),IOP(3,8) /4HDISP,4HL   ,4H   /           STO11800
      DATA IOP(1,9),IOP(2,9),IOP(3,9) /4HLOAD,4HI   ,4H   /           STO11810
      DATA IOP(1,10),IOP(2,10),IOP(3,10) /4HPLAN,4HE   ,4H   /        STO11820
      DATA IOP(1,11),IOP(2,11),IOP(3,11) /4HSLOP,4HE   ,4H   /        STO11830
      DATA IOP(1,12),IOP(2,12),IOP(3,12) /4HADDK,4H    ,4H   /        STO11840
      DATA IOP(1,13),IOP(2,13),IOP(3,13) /4HEMFR,4HC   ,4H   /        STO11850
      DATA IOP(1,14),IOP(2,14),IOP(3,14) /4HFRAM,4HE   ,4H   /        STO11860
      NUMOP=14                                                        STO11870
      GO TO 175                                                       STO11880
C---- READ OPERATION FROM CARD OR STORAGE  ----------------           STO11890
  100 CALL INPUT(IERR)                                                STO11900
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      IF(IERR .GT. 1) RETURN                                            STO11910
C-----INTERPRETE OPERATION ---------------------------------            STO11920
  175 DO 200 J=1,NUMOP                                                  STO11930
      N=J                                                               STO11940
      IF (COMP(INHOL(1,1),IOP(1,J))) GO TO 300                          STO11950
  200 CONTINUE                                                          STO11960
      RETURN                                                            STO11970
C-----EXECUTE APPROPRIATE OPERATION ----------------------              STO11980
  300 LAST=2                                                            STO11990
      CALL STRUC(N,IERR)                                                STO12000
      IF(IERR .GT. 1) RETURN                                            STO12010
      GO TO 100                                                         STO12020
      END                                                               STO12030
      SUBROUTINE STRUC(NOP,IERR)                                        STO12040
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO12050
      COMMON MTOT,NDP,L(1)                                              STO12060
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO12070
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                       STO12080
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)            STO12090
      COMMON /ADIR/ NA,I(10)                                            STO12100
      COMMON /PSAVE/ NUMNP,NEQ,NPROP,NUMEL,NTRUSS                       STO12110
      EQUIVALENCE (M1,INHOL(1,2)),(M2,INHOL(1,3)),(M3,INHOL(1,4))       STO12120
      EQUIVALENCE (M4,INHOL(1,5)),(M5,INHOL(1,6)),(M6,INHOL(1,7))       STO12130
      DATA IBLANK/4H    /                                               STO12140
      GO TO (100,200,300,300,500,600,700,800,900,300,910,920,930,940),  STO12150
     1  NOP                                                             STO12160
C-----READ NODE COORDINATES-------------------------                    STO12170
  100 CALL DELETE(M1)                                                   STO12180
      NUMNP=N1                                                          STO12190
      CALL LIST(M1,N1,3,NDP,IERR)                                       STO12200
      IF(IERR .GT. 1) RETURN                                            STO12210
      CALL NODES(L(NA),N1)                                              STO12220
      RETURN                                                            STO12230
C-----SPECIFICATION OF DISPLACEMENT BOUNDARY CONDITIONS                 STO12240
  200 CALL DELETE(M1)                                                   STO12250
      CALL LIST(M1,NUMNP,6,NSP,IERR)                                    STO12260
      IF(IERR .GT. 1) RETURN                                            STO12270
      CALL BOUND(L(NA),NUMNP,NEQ)                                       STO12280
      CALL PTAPE(1,1)                                                   STO12290
      NUMEL=0                                                           STO12300
      RETURN                                                            STO12310
C-----CALCULATION OF TRUSS AND BEAM STIFFNESS MATRICES------            STO12320
  300 CALL FIND(M2,IERR)                                                STO12330
      IF(IERR .GT. 1) RETURN                                            STO12340
      NC=N1                                                             STO12350
      NE=N2                                                             STO12360
      N1=NA                                                             STO12370
      CALL FIND(M3,IERR)                                                STO12380
      IF(IERR .GT. 1) RETURN                                            STO12390
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      N2=NA                                                              STO12400
      CALL FIND(M4,IERR)                                                 STO12410
      IF(IERR .GT. 1) RETURN                                             STO12420
      NPROP=I(4)                                                         STO12430
      N3=N1+NUMNP*NDP                                                    STO12440
      N4=N1+2*NUMNP*NDP                                                  STO12450
      IF(NOP.EQ.10) GO TO 370                                            STO12460
      IF(NOP.EQ.4) GO TO 350                                             STO12470
C-----CALCULATION OF TRUSS ELEMENT MATRICES-----NOP=3                    STO12480
      ND=6                                                               STO12490
      NS=1                                                               STO12500
      CALL TRUSS(L(N1),L(N3),L(N4),L(N2),L(NA),NUMNP,NTRUSS,NPROP)       STO12510
      GO TO 400                                                          STO12520
C-----CALCULATION OF BEAM ELEMENT STIFFNESS MATRICES-- NOP=4             STO12530
  350 ND=12                                                              STO12540
      NS=3                                                               STO12550
      CALL BEAM(L(N1),L(N3),L(N4),L(N2),L(NA),NUMNP,NTRUSS,NPROP)        STO12560
      GO TO 400                                                          STO12570
C-----CALCULATION OF 3 TO 8 NODE FINITE ELEMENT---                       STO12580
  370 ND=16                                                              STO12590
      NS=9                                                               STO12600
      CALL PLANE(L(N1),L(N3),L(N4),L(N2),L(NA),NUMNP,NTRUSS,NPROP,NC,NE) STO12610
  400 CALL DELETE(M1)                                                    STO12620
      CALL LIST(M1,1,5,NSP,IERR)                                         STO12630
      IF(IERR .GT. 1) RETURN                                             STO12640
      L(NA)=NTRUSS                                                       STO12650
      L(NA+1)=ND                                                         STO12660
      L(NA+2)=NS                                                         STO12670
      L(NA+4)=NUMEL+1                                                    STO12680
      NUMEL=NUMEL+NTRUSS                                                 STO12690
      RETURN                                                             STO12700
C------FORMATION OF TOTAL STIFFNESS AND MASS MATRICES                   STO12710
  500 CALL DELETE(M1)                                                    STO12720
      IF(M2.NE.IBLANK) CALL DELETE(M2)                                   STO12730
      CALL RTAPE(1,1)                                                    STO12740
      IF(I2.EQ.IBLANK) GO TO 550                                         STO12750
      CALL LIST(M2,NEQ,1,NDP,IERR)                                       STO12760
      IF(IERR .GT. 1) RETURN                                             STO12770
      N1=NA                                                              STO12780
  550 CALL LIST(M1,NEQ,NEQ,NDP,IERR)                                     STO12790
      IF(IERR .GT. 1) RETURN                                             STO12800
      CALL ADDSF(L(NA),L(N1),NEQ,NUMEL,M2)                               STO12810
      RETURN                                                             STO12820
C-----FORMATION OF LOAD MATRIX--------------------                       STO12830
  600 CALL DELETE(M1)                                                    STO12840
      CALL FIND(M2,IERR)                                                 STO12850
      IF(IERR .GT. 1) RETURN                                             STO12860
      N2=NA                                                              STO12870
      CALL LIST(M1,NEQ,N1,NDP,IERR)                                      STO12880
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      IF(IERR .GT. 1) RETURN                                          STO12890
      CALL LOADS(L(N2),L(NA),NEQ,N1,NUMNP)                            STO12900
      RETURN                                                          STO12910
C-----EVALUATION OF MEMBER FORCES                                     STO12920
  700 CALL FIND(M1,IERR)                                              STO12930
      IF(IERR .GT. 1) RETURN                                          STO12940
      NUME=L(NA)                                                      STO12950
      ND=L(NA+1)                                                      STO12960
      NSS=0                                                           STO12970
      NS=L(NA+2)                                                      STO12980
      NR=L(NA+4)                                                      STO12990
      CALL PTAPE(1,NR)                                                STO13000
      CALL FIND(M2,IERR)                                              STO13010
      IF(IERR .GT. 1) RETURN                                          STO13020
      N1=NA                                                           STO13030
      NL=L(3)                                                         STO13040
      IF(M3.EQ.IBLANK) GO TO 1050                                     STO13050
      NSS=NS*NUME                                                     STO13060
      CALL LIST(M3,NSS,NL,NDP,IERR)                                   STO13070
      IF(IERR .GT. 1) RETURN                                          STO13080
 1050 CALL FORCE(L(N1),L(NA),NEQ,NL,NUME,NSS)                         STO13090
      RETURN                                                          STO13100
C-----PRINT OF NODE DISPLACEMENTS-------------------                  STO13110
  800 IF(NO.NE.0) RETURN                                              STO13120
      CALL FIND(M1,IERR)                                              STO13130
      IF(IERR .GT. 1) RETURN                                          STO13140
      N2=NA                                                           STO13150
      NL=L(3)                                                         STO13160
      CALL FIND(M2,IERR)                                              STO13170
      IF(IERR .GT. 1) RETURN                                          STO13180
      CALL DISPL(L(N2),L(NA),NEQ,NL,NUMNP)                            STO13190
      RETURN                                                          STO13200
C-----  LOAD INTERGER ARRAY-----------------------                    STO13210
  900 CALL DELETE(M1)                                                 STO13220
      CALL LIST(M1,N1,N2,NSP,IERR)                                    STO13230
      IF(IERR .GT. 1) RETURN                                          STO13240
      CALL LOADI(L(NA),N1,N2,N3,N4)                                   STO13250
      RETURN                                                          STO13260
C-----FORM 4 X 4 BEAM STIFFNESS MATRIX---------------                 STO13270
  910 CALL DELETE(M1)                                                 STO13280
      CALL LIST(M1,4,4,NDP,IERR)                                      STO13290
      IF(IERR .GT. 1) RETURN                                          STO13300
      CALL SLOPE(L(NA))                                               STO13310
      RETURN                                                          STO13320
C-----ADD ELEMENT STIFFNESS TO TOTAL STIFFNESS----------              STO13330
  920 CALL LOCATE(MI,NK,NR,NEQ,IERR)                                  STO13340
      IF(NR.NE.NEQ)CALL ERCOM(IERR)                                   STO13350
      IF(IERR.GT.1)RETURN                                             STO13360
      CALL LOCATE(M2,NE,NR,NC,IERR)                                   STO13370
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      IF(NR.NE.NC)CALL ERCOM(IERR)                                      STO13380
      IF(IERR .GT. 1) RETURN                                            STO13390
      CALL LOCATE(M3,NL,ND,NC,IERR)                                     STO13400
      IF(NR.NE.ND)CALL ERCOM(IERR)                                      STO13410
      IF(IERR .GT. 1) RETURN                                            STO13420
      NL=NL+NR*(N1-1)                                                   STO13430
      CALL ADDK(L(NK),L(NE),L(NL),NR,NEQ)                               STO13440
      RETURN                                                            STO13450
C-----CALCULATE MEMBER FORCES--------------------------                 STO13460
  930 CALL DELETE(M4)                                                   STO13470
      CALL LOCATE(M1,NE,NR,NC,IERR)                                     STO13480
      CALL LOCATE(M2,ND,NEQ,NL,IERR)                                    STO13490
      CALL LOCATE(M3,N2,N3,N4,IERR)                                     STO13500
      N2=N3+N2*(N1-1)                                                   STO13510
      CALL LIST(M4,NR,NL,NDP,IERR)                                      STO13520
      IF(IERR .GT. 1) RETURN                                            STO13530
      CALL MEMPRC(L(NE),L(ND),L(N2),L(NA),NR,NC,NEQ,NL)                 STO13540
      RETURN                                                            STO13550
C-----CALCULATION OF 2D FRAME MATRICES- 6 DOF --------                   STO13560
  940 CALL DELETE(M1)                                                   STO13570
      CALL DELETE (M2)                                                  STO13580
      CALL LIST(M1,6,6,NDP,IERR)                                        STO13590
      NK=NA                                                             STO13600
      CALL LIST(M2,3,6,NDP,IERR)                                        STO13610
      IF(IERR .GT. 1)RETURN                                             STO13620
      CALL FRAME(L(NK),L(NA))                                           STO13630
      RETURN                                                            STO13640
      END                                                               STO13650
      SUBROUTINE LOCATE(M1,NT,NR,NC,IERR)                               STO13660
      COMMON /ADIR/ NA,I(10)                                            STO13670
      DIMENSION M1(1)                                                   STO13680
      CALL FIND(M1,IERR)                                                STO13690
      NT=NA                                                             STO13700
      NC=I(3)                                                           STO13710
      NR=I(4)                                                           STO13720
      RETURN                                                            STO13730
      END                                                               STO13740
      SUBROUTINE ADDSP(A,B,NEQ,NUMEL,M2)                                STO13750
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO13760
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)            STO13770
      DIMENSION A(NEQ,1),B(1)                                           STO13780
      DATA IBLANK/4H    /                                               STO13790
C                                                                       STO13800
      DO 100 I=1,NEQ                                                    STO13810
      IF(M2.NE.IBLANK) B(I)=0.0D0                                       STO13820
      DO 100 J=1,NEQ                                                    STO13830
  100 A(I,J)=0.0D0                                                      STO13840
      DO 300 N=1,NUMEL                                                  STO13850
      CALL PTAPE(3,NR)                                                  STO13860
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      DO 200 I=1,ND                                                     STO13870
      II=LM(I)                                                          STO13880
      IF(II.LE.0) GO TO 200                                             STO13890
      IF(M2.NE.IBLANK) B(II)=B(II)+XM(I)                                STO13900
      DO 150 J=1,ND                                                     STO13910
      JJ=LM(J)                                                          STO13920
      IF(JJ.LE.0) GO TO 150                                             STO13930
      A(II,JJ)=A(II,JJ)+S(I,J)                                          STO13940
  150 CONTINUE                                                          STO13950
  200 CONTINUE                                                          STO13960
  300 CONTINUE                                                          STO13970
      RETURN                                                            STO13980
      END                                                               STO13990
      SUBROUTINE ADDK(A,S,LM,NR,NEQ)                                    STO14000
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO14010
      DIMENSION A(NEQ,1),S(NR,1),LM(NR)                                 STO14020
C-----ADDITION OF MEMBER STIFFNESS TO TOTAL STIFFNESS-----              STO14030
      DO 400 I=1,NR                                                     STO14040
      II=LM(I)                                                          STO14050
      IF(II.EQ.0)GO TO 400                                              STO14060
      DO 300 J=1,NR                                                     STO14070
      JJ=LM(J)                                                          STO14080
      IF(JJ.EQ.0)GO TO 300                                              STO14090
      A(II,JJ)=A(II,JJ)+S(I,J)                                          STO14100
  300 CONTINUE                                                          STO14110
  400 CONTINUE                                                          STO14120
      RETURN                                                            STO14130
      END                                                               STO14140
      SUBROUTINE SLOPE(S)                                               STO14150
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO14160
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR,INDIC       STO14170
      DIMENSION S(4,1)                                                  STO14180
      READ(NREAD,1000) XI,E,XL                                          STO14190
      IF(NO.EQ.0) WRITE(NWRITE,2000) XI,E,XL                            STO14200
      EIL=E*XI/XL                                                       STO14210
      S(1,1)=4.0D0*EIL                                                  STO14220
      S(1,2)=2.0D0*EIL                                                  STO14230
      S(1,3)=-6.0D0*EIL/XL                                              STO14240
      S(1,4)=-S(1,3)                                                    STO14250
      S(2,2)=S(1,1)                                                     STO14260
      S(2,3)=S(1,3)                                                     STO14270
      S(2,4)=S(1,4)                                                     STO14280
      S(3,3)=12.0D0*EIL/(XL*XL)                                         STO14290
      S(3,4)=-S(3,3)                                                    STO14300
      S(4,4)=S(3,3)                                                     STO14310
      DO 100 J=1,3                                                      STO14320
      JP1 = J + 1                                                       STO14330
      DO 100 I = JP1,4                                                  STO14340
  100 S(I,J)=S(J,I)                                                     STO14350
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      RETURN                                                            STO14360
 1000 FORMAT(3F10.0)                                                    STO14370
 2000 FORMAT(4H I= ,1PD15.6,5H  E= ,1PD15.6,5H  L= ,1PD15.6)            STO14380
      END                                                               STO14390
      SUBROUTINE FRAME(S,A)                                             STO14400
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO14410
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR,INDIC       STO14420
      DIMENSION S(6,1),A(3,1)                                           STO14430
C-------------------------------------                                  STO14440
      READ(NREAD,1000)AR,E,XI,X1,Y1,X2,Y2                               STO14450
      IF(NO.EQ.0)WRITE(NWRITE,2000)AR,E,XI,X1,Y1,X2,Y2                  STO14460
      DX=X2-X1                                                          STO14470
      DY = Y2-Y1                                                        STO14480
      XL = DSQRT(DX*DX+DY*DY)                                           STO14490
      SIN=DY/XL                                                         STO14500
      COS=DX/XL                                                         STO14510
C -------------------------------------                                STO14520
      A(1,1) =  SIN/XL                                                  STO14530
      A(1,2) =-COS/XL                                                   STO14540
      A(1,3) =1.0D0                                                     STO14550
      A(1,4) =-A(1,1)                                                   STO14560
      A(1,5) =-A(1,2)                                                   STO14570
      A(1,6) =0.0D0                                                     STO14580
      A(2,1) =  SIN/XL                                                  STO14590
      A(2,2) =-COS/XL                                                   STO14600
      A(2,3) =0.0D0                                                     STO14610
      A(2,4) =A(1,4)                                                    STO14620
      A(2,5) =A(1,5)                                                    STO14630
      A(2,6) =1.0D0                                                     STO14640
      A(3,1) =-COS                                                      STO14650
      A(3,2) =-SIN                                                      STO14660
      A(3,3) =0.0D0                                                     STO14670
      A(3,4) =COS                                                       STO14680
      A(3,5) =SIN                                                       STO14690
      A(3,6) =0.0D0                                                     STO14700
C-------------------------------------                                  STO14710
      S12=2.0D0*E*XI/XL                                                 STO14720
      S11=S12+S12                                                       STO14730
      S33=AR*E/XL                                                       STO14740
C-------------------------------------                                  STO14750
      DO 300 I=1,6                                                      STO14760
      T1=S11*A(1,I)+S12*A(2,I)                                          STO14770
      T2=S12*A(1,I)+S11*A(2,I)                                          STO14780
      T3=S33*A(3,I)                                                     STO14790
      DO 200 J=1,6                                                      STO14800
      S(J,I)=A(1,J)*T1+A(2,J)*T2+A(3,J)*T3                              STO14810
  200 S(I,J)=S(J,I)                                                     STO14820
      A(1,I)=T1                                                         STO14830
      A(2,I)=T2                                                         STO14840
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      A(3,I)=T3                                                          STO14850
  300 CONTINUE                                                           STO14860
      RETURN                                                             STO14870
 1000 FORMAT(7F10.0)                                                     STO14880
 2000 FORMAT(14X,1HA,14X,1HE,14X,1HI,13X,2HX1,13X,2HY1,                  STO14890
     1  13X,2HX2,13X,2HY2,/(7F15.4))                                    STO14900
      END                                                                STO14910
      SUBROUTINE MEMFRC(S,U,LM,F,NR,NC,NEQ,NL)                           STO14920
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO14930
      DIMENSION S(NR,NC),U(NEQ,NL),LM(NC),F(NR,NL)                       STO14940
C-----EVALUATION OF MEMBER FORCES-----------                             STO14950
      DO 100 I=1,NR                                                      STO14960
      DO 100 L=1,NL                                                      STO14970
      SUM=0.0D0                                                          STO14980
      DO 50 K = 1,NC                                                     STO14990
      KK=LM(K)                                                           STO15000
      IF(KK.EQ.0)GO TO 50                                                STO15010
      SUM=SUM +S(I,K)*U(KK,L)                                            STO15020
   50 CONTINUE                                                           STO15030
      F(I,L)=SUM                                                         STO15040
  100 CONTINUE                                                           STO15050
      RETURN                                                             STO15060
      END                                                                STO15070
      SUBROUTINE TRUSS(X,Y,Z,ID,EE,NUMNP,NTRUSS,NPROP)                   STO15080
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO15090
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR              STO15100
      DIMENSION X(1),Y(1),Z(1),ID(NUMNP,6),EE(NPROP,3)                   STO15110
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)             STO15120
C-------EVALUATION OF TRUSS ELEMENT MATRICES-------                      STO15130
      NTRUSS=0                                                           STO15140
      IF(NO.EQ.0) WRITE(NWRITE,2000)                                     STO15150
  100 READ(NREAD,1001)M,I,J,NP,NPT                                       STO15160
      IF(M.EQ.0)  RETURN                                                 STO15170
      AREA=EE(NP,1)                                                      STO15180
      E=EE(NP,2)                                                         STO15190
      DEN=EE(NP,3)                                                       STO15200
      IF(NO.EQ.0)  WRITE(NWRITE,2001)  M,I,J,AREA,E,DEN                  STO15210
      DX=X(I)-X(J)                                                       STO15220
      DY=Y(I)-Y(J)                                                       STO15230
      DZ=Z(I)-Z(J)                                                       STO15240
      XL2=DX*DX+DY*DY+DZ*DZ                                              STO15250
      XL=DSQRT(XL2)                                                      STO15260
      DEN=DEN*XL/2.D0                                                    STO15270
      XX=E*AREA/XL                                                       STO15280
      ST(1,1)=DX/XL                                                      STO15290
      ST(1,2)=DY/XL                                                      STO15300
      ST(1,3)=DZ/XL                                                      STO15310
      ST(1,4)=-ST(1,1)                                                   STO15320
      ST(1,5)=-ST(1,2)                                                   STO15330
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      ST(1,6)=-ST(1,3)                                                          STO15340
C                                                                               STO15350
      DO 300 L=1,6                                                              STO15360
      YY=ST(1,L)*XX                                                             STO15370
      DO 250 K=L,6                                                              STO15380
      S(K,L)=ST(1,K)*YY                                                         STO15390
  250 S(L,K)=S(K,L)                                                             STO15400
      ST(1,L)=YY                                                                STO15410
  300 XM(L)=DEN                                                                 STO15420
      DO 400 L=1,3                                                              STO15430
      LM(L)=ID(I,L)                                                             STO15440
  400 LM(L+3)=ID(J,L)                                                           STO15450
      CALL PTAPE(2,NR)                                                          STO15460
      NTRUSS=NTRUSS+1                                                           STO15470
      GO TO 100                                                                 STO15480
C                                                                               STO15490
 1001 FORMAT(5I5)                                                               STO15500
 2000 FORMAT( 7HONUMBER 6X 1HI 6X 1HJ 11X 4HAREA 14X 1HE 12X 3HDEN )            STO15510
 2001 FORMAT (3I7,F15.3,2(1PD15.6))                                             STO15520
      END                                                                       STO15530
      SUBROUTINE BEAM(X,Y,Z,ID,P,NUMNP,NUME,NP)                                 STO15540
      IMPLICIT REAL*8 (A-H,O-Z)                                                 STO15550
      DIMENSION X(NUMNP),Y(NUMNP),Z(NUMNP),ID(NUMNP,6),P(NP,7)                  STO15560
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                     STO15570
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)                    STO15580
      COMMON /TEMP/ A(6,12),T(3,3),V(4,4)                                       STO15590
C-----READ AND PRINT BEAM DATA--------------------                             STO15600
      NUME=0                                                                    STO15610
      IF(NO.EQ.0) WRITE(NWRITE,2000)                                            STO15620
  100 READ(NREAD,1000) N,I,J,K,NN                                               STO15630
      IF(N.EQ.0) RETURN                                                         STO15640
      IF(NO.EQ.0) WRITE(NWRITE,2001) N,I,J,K,NN,(P(NN,L),L=1,7)                 STO15650
      NUME=NUME+1                                                               STO15660
C-----FORM 3 X 3 TRANSFORMATION MATRX ------------                             STO15670
      CALL VECTOR(V(1,1),X(I),Y(I),Z(I),X(J),Y(J),Z(J))                         STO15680
      XL=V(4,1)                                                                 STO15690
      CALL VECTOR(V(1,4),X(I),Y(I),Z(I),X(K),Y(K),Z(K))                         STO15700
      CALL CROSS(V(1,1),V(1,4),V(1,3))                                          STO15710
      CALL CROSS(V(1,3),V(1,1),V(1,2))                                          STO15720
      DO 200 K=1,3                                                              STO15730
      DO 200 L=1,3                                                              STO15740
  200 T(K,L)=V(L,K)                                                             STO15750
C-----FORM DESTINATION VECTOR --------------------                             STO15760
      DO 300 L=1,6                                                              STO15770
      LM(L)=ID(I,L)                                                             STO15780
  300 LM(L+6)=ID(J,L)                                                           STO15790
C-----FORM STIFFNESS MATRIX IN LOCAL SYSTEM-------                             STO15800
      DO 400 I=1,6                                                              STO15810
      DO 400 J=1,6                                                              STO15820
```

```
  400 S(I,J)=0.0D0                                                      STO15830
      S(1,1)=P(NN,1)*P(NN,5)/XL                                         STO15840
      S(4,4)=P(NN,2)*P(NN,6)/XL                                         STO15850
      Q=4.D0*P(NN,5)/XL                                                 STO15860
      S(5,5)=Q*P(NN,3)                                                  STO15870
      S(6,6)=Q*P(NN,4)                                                  STO15880
      Q=3.D0/(XL*XL)                                                    STO15890
      S(3,3)=Q*S(5,5)                                                   STO15900
      S(2,2)=Q*S(6,6)                                                   STO15910
      Q=1.5D0/XL                                                        STO15920
      S(2,6)=-Q*S(6,6)                                                  STO15930
      S(6,2)=S(2,6)                                                     STO15940
      S(3,5)=Q*S(5,5)                                                   STO15950
      S(5,3)=S(3,5)                                                     STO15960
C-----FORM LOCAL-GLOBAL TRANSFORMATION----------                        STO15970
      DO 500 I=1,6                                                      STO15980
      DO 500 J=1,12                                                     STO15990
  500 A(I,J)=0.0D0                                                      STO16000
      DO 500 J=1,3                                                      STO16010
      A(2,J+3)=-XL*T(3,J)                                               STO16020
      A(3,J+3)= XL*T(2,J)                                               STO16030
      DO 500 I=1,3                                                      STO16040
      A(I,J)=-T(I,J)                                                    STO16050
      A(I+3,J+3)=-T(I,J)                                                STO16060
      A(I,J+6)=T(I,J)                                                   STO16070
  500 A(I+3,J+9)=T(I,J)                                                 STO16080
C-----  FORM GLOBAL STIFFNESS MATRIX                                    STO16090
      DO 300 I=1,6                                                      STO16100
      DO 300 J=1,12                                                     STO16110
      ST(I,J)=0.0D0                                                     STO16120
      DO 300 K=1,6                                                      STO16130
  800 ST(I,J)=ST(I,J)+S(I,K)*A(K,J)                                     STO16140
      DO 900 I=1,12                                                     STO16150
      ST(7,I)= ST(3,I)*XL-ST(5,I)                                       STO16160
      ST(8,I)=-ST(2,I)*XL-ST(6,I)                                       STO16170
      DO 900 J=I,12                                                     STO16180
      Q=0.0D0                                                           STO16190
      DO 850 K=1,6                                                      STO16200
  850 Q=Q+A(K,I)*ST(K,J)                                                STO16210
      S(I,J)=Q                                                          STO16220
  900 S(J,I)=Q                                                          STO16230
C-----CALCULATE MASS MATRIX ----------------------                     STO16240
      XMASS=P(NN,7)*XL/2.D0                                             STO16250
      V(1,1)=XMASS*P(NN,2)/P(NN,1)                                      STO16260
      V(2,1)=XMASS*XL*XL/12.D0                                          STO16270
      V(3,1)=V(2,1)                                                     STO16280
      DO 950 I=1,3                                                      STO16290
      XM(I)=XMASS                                                       STO16300
      XM(I+6)=XMASS                                                     STO16310
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```
      XM(I+3)=0.0D0                                                          STO16320
      DO 950 J=1,3                                                           STO16330
  950 XM(I+3)=XM(I+3)+T(J,I)*V(J,1)                                          STO16340
      XM(I+3)=DABS(XM(I+3))                                                  STO16350
  960 XM(I+9)=XM(I+3)                                                        STO16360
C-----STORE ELEMENT MATRICES ON LOW SPEED STORAGE--                          STO16370
      CALL PTAPE(2,NR)                                                       STO16380
      GO TO 100                                                              STO16390
 1000 FORMAT(5I5)                                                            STO16400
 2000 FORMAT (25H0 EL.     I     J     K    NP 9X,1HA,7X,3HJ11,7X,3HI22,7X,  STO16410
     1 3HI33,9X,1HE,9X,1HG,9X,1HM )                                          STO16420
 2001 FORMAT (5I5,1P10.2,5P10.0,P10.4)                                       STO16430
      END                                                                    STO16440
      SUBROUTINE VECTOR(V,XI,YI,ZI,XJ,YJ,ZJ)                                 STO16450
      IMPLICIT REAL*8 (A-H,O-Z)                                              STO16460
      DIMENSION V(4)                                                         STO16470
      X=XJ-XI                                                                STO16480
      Y=YJ-YI                                                                STO16490
      Z=ZJ-ZI                                                                STO16500
      V(4)=DSQRT(X*X+Y*Y+Z*Z)                                                STO16510
      V(3)=Z/V(4)                                                            STO16520
      V(2)=Y/V(4)                                                            STO16530
      V(1)=X/V(4)                                                            STO16540
      RETURN                                                                 STO16550
      END                                                                    STO16560
      SUBROUTINE CROSS(A,B,C)                                                STO16570
      IMPLICIT REAL*8 (A-H,O-Z)                                              STO16580
      DIMENSION A(4),B(4),C(4)                                               STO16590
      X=A(2)*B(3)-A(3)*B(2)                                                  STO16600
      Y=A(3)*B(1)-A(1)*B(3)                                                  STO16610
      Z=A(1)*B(2)-A(2)*B(1)                                                  STO16620
      C(4)=DSQRT(X*X+Y*Y+Z*Z)                                                STO16630
      C(3)=Z/C(4)                                                            STO16640
      C(2)=Y/C(4)                                                            STO16650
      C(1)=X/C(4)                                                            STO16660
      RETURN                                                                 STO16670
      END                                                                    STO16680
      SUBROUTINE PLANE(X,Y,Z,ID,P,NUMNP,NUME,NP,INR,INS)                     STO16690
      IMPLICIT REAL*8 (A-H,O-Z)                                              STO16700
      DIMENSION X(NUMNP),Y(NUMNP),Z(NUMNP),ID(NUMNP,6),P(NP,4)               STO16710
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                  STO16720
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)                 STO16730
      COMMON /TEMP/ H(3,8),IZ(2,8),B(3,16),NODE(8),DJ,NN                     STO16740
C---- POINTS AND WEIGHTS FOR 1 TO 3 POINT INTEGRATION-----                   STO16750
      DIMENSION RSI(3,3),WGT(3,3),RS(2,3)                                    STO16760
      DATA RSI/ 0.D0, 0.D0, 0.D0, -.577350269189626D0, 0.577350269189626 STO16770
     1D0,  0.0D0, -0.774596669241483D0, 0.0D0, 0.774596669241483 D0/    STO16780
      DATA WGT/ 2.0D0, 0.0D0, 0.0D0, 1.0D0, 1.0D0, 0.0D0, 0.555555555555 STO16790
     1556D0,          0.888888888888889D0, 0.555555555555556 D0/        STO16800
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      IF(INR.LT.1) INR=2                                                        STO16810
      IF(INR.GT.3) INR=3                                                        STO16820
      IF(INS.LT.1) INS=2                                                        STO16830
      IF(INS.GT.3) INS=3                                                        STO16840
      IF(NO.EQ.0) WRITE(NWRITE,2002)INR,INS                                     STO16850
 2002 FORMAT (22H NUMERICAL INTEGRATION 2I3,22H IN R AND S DIRECTIONS )         STO16860
C-----READ AND PRINT ELEMENT DATA-----------------                              STO16870
      NUME=0                                                                    STO16880
      IF(NO.EQ.0) WRITE(NWRITE,2000)                                            STO16890
  100 READ(NREAD,1000) N,NODE,NN,RS                                             STO16900
      IF(N.EQ.0) RETURN                                                         STO16910
      IF (NO.EQ.0) WRITE(NWRITE,2001)N,NODE,(P(NN,L),L=1,4),RS                  STO16920
      THK=P(NN,3)                                                               STO16930
      IF(THK.EQ.0.0D0) THK=1.0D0                                                STO16940
      DEN=P(NN,4)                                                               STO16950
      VOL=0.D0                                                                  STO16960
C-----ZERO STIFFNESS ----------------------------                              STO16970
      DO 200 I=1,16                                                             STO16980
      XM(I)=0.0D0                                                               STO16990
      DO 200 J=1,16                                                             STO17000
  200 S(I,J)=0.000                                                              STO17010
C-----FORM STRESS-STRAIN MATRIX--------------------                            STO17020
      C11=P(NN,1)/(1.D0-P(NN,2)*P(NN,2))                                        STO17030
      C12=C11*P(NN,2)                                                           STO17040
      C33=C11*(1.D0+P(NN,2))/2.D0                                               STO17050
C-----SELECT NODE COORDINATES AND DESTINATION VECTOR                            STO17060
      J=0                                                                       STO17070
      DO 250 I=1,8                                                              STO17080
      II=NODE(I)                                                                STO17090
      IF(II) 250,250,240                                                        STO17100
  240 J=J+1                                                                     STO17110
      YZ(1,J)=Y(II)                                                             STO17120
      YZ(2,J)=Z(II)                                                             STO17130
      LM(2*J-1)=ID(II,2)                                                        STO17140
      LM(2*J)=ID(II,3)                                                          STO17150
  250 CONTINUE                                                                  STO17160
      NN=J                                                                      STO17170
      ND=2*NN                                                                   STO17180
C-----FORM BT*C*B FOR EACH INTEGRATION POINT------                             STO17190
      DO 400 IR=1,INR                                                           STO17200
      DO 400 IS=1,INS                                                           STO17210
      CALL FORMB(RSI(IR,INR),RSI(IS,INS))                                       STO17220
      DV=WGT(IR,INR)*WGT(IS,INS)*DJ*THK                                         STO17230
      VOL=VOL+DV                                                                STO17240
      DO 300 J=1,NN                                                             STO17250
  300 XM(J)=XM(J)+H(1,J)*H(1,J)*DV                                              STO17260
      DO 400 J=1,ND                                                             STO17270
      CB1=C11*B(1,J)+C12*B(2,J)                                                 STO17280
      CB2=C12*B(1,J)+C11*B(2,J)                                                 STO17290
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      CB3=C33*B(3,J)                                                    STO17300
      DO 400 I=J,ND                                                     STO17310
      SUM=B(1,I)*CB1+B(2,I)*CB2+B(3,I)*CB3                              STO17320
      S(I,J)=S(I,J)+DV*SUM                                              STO17330
  400 S(J,I)=S(I,J)                                                     STO17340
C-----FORM STRESS DISPLACEMENT TRANSFORMATION MATRIX                    STO17350
      DO 500 I=1,3                                                      STO17360
      CALL FORMB(RS(1,I),RS(2,I))                                       STO17370
      JJ=3*(I-1)+1                                                      STO17380
      DO 500 J=1,ND                                                     STO17390
      ST(JJ  ,J)=C11*B(1,J)+C12*B(2,J)                                  STO17400
      ST(JJ+1,J)=C12*B(1,J)+C11*B(2,J)                                  STO17410
  500 ST(JJ+2,J)=C33*B(3,J)                                             STO17420
C-----FORM DIAGONAL MASS MATRIX-------------------                      STO17430
      FAC=0.0D0                                                         STO17440
      DO 550 J=1,NN                                                     STO17450
  550 FAC=FAC+XM(I)                                                     STO17460
      FAC=VOL*DEN/FAC                                                   STO17470
      DO 580 J=1,NN                                                     STO17480
  580 YZ(1,J)=XM(J)*FAC                                                 STO17490
      DO 600 J=1,NN                                                     STO17500
      XM(2*J)=YZ(1,J)                                                   STO17510
  600 XM(2*J-1)=YZ(1,J)                                                 STO17520
C-----WRITE ELEMENT MATRICES ON TAPE-------------                       STO17530
      CALL PTAPE(2,NR)                                                  STO17540
      NUME=NUME+1                                                       STO17550
      GO TO 100                                                         STO17560
C-------------------------------------------------                      STO17570
 1000 FORMAT (10I5,6F5.0)                                               STO17580
 2000 FORMAT (116HONODE   N1   N2   N3   N4   N5   N6   N7   N8       STO17590
     1E        NU          T         M   R1   S1   R2   S2   R3   S3 )  STO17600
 2001 FORMAT(9I5,4(1PD10.3),6F5.2)                                      STO17610
      END                                                               STO17620
      SUBROUTINE FORMB(R,S)                                             STO17630
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO17640
      COMMON /TEMP/ H(3,8),YZ(2,8),B(3,16),NODE(8),DJ,NN                STO17650
C------FORM INTERPOLATION FUNCTIONS AND DERIVATIVES---                 STO17660
      CALL FORMH(R,S)                                                   STO17670
C------FORM B MATRIX -----------------------------                     STO17680
      DO 500 L=1,NN                                                     STO17690
      K=2*L-1                                                           STO17700
      B(1,K)=H(2,L)                                                     STO17710
      B(1,K+1)=0.0D0                                                    STO17720
      B(2,K)=0.0D0                                                      STO17730
      B(2,K+1)=H(3,L)                                                   STO17740
      B(3,K)=H(3,L)                                                     STO17750
  600 B(3,K+1)=H(2,L)                                                   STO17760
      RETURN                                                            STO17770
      END                                                               STO17780
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      SUBROUTINE FORMH(R,S)                                              STO17790
      IMPLICIT REAL*8 (A-H,O-Z)                                          STO17800
      COMMON /PSIZE/ NJ,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR              STO17810
      COMMON /TEMP/ H(3,8),YZ(2,8),B(3,16),NODE(8),DJ,NN                 STO17820
      DIMENSION N(2,8),D(2,2)                                            STO17830
      DATA N/1,1,-1,1,-1,-1,1,-1,0,1,-1,0,0,-1,1,0/                      STO17840
C-----FORM INTERPOLATION FUNCTIONS AND DERIVATIVES---                    STO17850
      DO 200 I=1,8                                                       STO17860
      CALL GD(R,N(1,I),GR,GRD)                                           STO17870
      CALL GD(S,N(2,I),GS,GSD)                                           STO17880
      H(1,I) = GR *GS                                                    STO17890
      H(2,I) = GRD*GS                                                    STO17900
  200 H(3,I) = GR *GSD                                                   STO17910
C-----MODIFY FOR NODES 5 TO 8 ----------------------------               STO17920
      M=4                                                                STO17930
      DO 300 I=5,8                                                       STO17940
      IF(NODE(I)) 300,300,250                                            STO17950
  250 M=M+1                                                              STO17960
      DO 290 K=1,3                                                       STO17970
      X=H(K,I)/2.D0                                                      STO17980
      H(K,M)=H(K,I)                                                      STO17990
      II=I-4                                                             STO18000
      H(K,II)=H(K,II)-X                                                  STO18010
      II=II+1                                                            STO18020
      IF(II.GT.4) II=1                                                   STO18030
  290 H(K,II)=H(K,II)-X                                                  STO18040
  300 CONTINUE                                                           STO18050
C-----CALCULATE JACOBIAN MATRIX----------------                          STO18060
      DO 400 I=1,2                                                       STO18070
      DO 400 J=1,2                                                       STO18080
      SUM=0.0D0                                                          STO18090
      DO 350 K=1,NN                                                      STO18100
  350 SUM=SUM+H(I+1,K)*YZ(J,K)                                           STO18110
  400 D(I,J)=SUM                                                         STO18120
C-----INVERT JACOBIAN MATRIX ---------------------                       STO18130
      DJ=D(1,1)*D(2,2)-D(1,2)*D(2,1)                                     STO18140
      IF(DJ.LE.0.0D0) WRITE(NWRITE,2000)DJ                               STO18150
      SUM=D(1,1)/DJ                                                      STO18160
      D(1,1)=D(2,2)/DJ                                                   STO18170
      D(1,2)=-D(1,2)/DJ                                                  STO18180
      D(2,1)=-D(2,1)/DJ                                                  STO18190
      D(2,2)=SUM                                                         STO18200
C-----CALCULATE H,Y AND H,Z ----------------------                       STO18210
      DO 500 K=1,NN                                                      STO18220
      HR=H(2,K)                                                          STO18230
      HS=H(3,K)                                                          STO18240
      H(2,K)=D(1,1)*HR+D(1,2)*HS                                         STO18250
  500 H(3,K)=D(2,1)*HR+D(2,2)*HS                                         STO18260
      RETURN                                                             STO18270
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 2000 FORMAT (10H JACOBIAN=  1PD15.6)                                   STO18280
      END                                                               STO18290
      SUBROUTINE GD(B,IB,G,D)                                           STO18300
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO18310
      IF(IB) 100,200,300                                                STO18320
  100 G=(1-B)/2.00                                                      STO18330
      D=-.5D0                                                           STO18340
      RETURN                                                            STO18350
  200 G=1.00-B*B                                                        STO18360
      D=-2.D0*B                                                         STO18370
      RETURN                                                            STO18380
  300 G=(1.00+B)/2.D0                                                   STO18390
      D=.500                                                            STO18400
      RETURN                                                            STO18410
      END                                                               STO18420
      SUBROUTINE PTAPE(NN,NR)                                           STO18430
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO18440
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)            STO18450
      COMMON /PSAVE/ NUMNP,NEQ,NPROP,NUMEL,NTRUSS,NT,NSAVE              STO18460
      GO TO (50,600,700),NN                                             STO18470
C-----POSITION TAPE-------------------------------                      STO18480
   50 IF(NR.NE.1) GO TO 100                                             STO18490
      REWIND NT                                                         STO18500
      NRP=1                                                             STO18510
  100 IF(NRP.EQ.NR) RETURN                                              STO18520
      NX=NR-NRP                                                         STO18530
      IF(NX.LT.0) GO TO 300                                             STO18540
      DO 200 N=1,NX                                                     STO18550
  200 READ (NT)                                                         STO18560
      GO TO 500                                                         STO18570
  300 NX=-NX                                                            STO18580
      DO 400 N=1,NX                                                     STO18590
  400 BACKSPACE NT                                                      STO18600
  500 NRP=NR                                                            STO18610
      RETURN                                                            STO18620
C-----WRITE  RECORD ON LOW SPEED STORAGE---------                       STO18630
  600 WRITE (NT) ST,XM,S,ND,NS,LM                                       STO18640
      NRP=NRP+1                                                         STO18650
      RETURN                                                            STO18660
  700 READ  (NT) ST,XM,S,ND,NS,LM                                       STO18670
      NRP=NRP+1                                                         STO18680
      RETURN                                                            STO18690
      END                                                               STO18700
      SUBROUTINE FORCE(D,P,NEQ,NL,NUME,NSS)                             STO18710
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO18720
      DIMENSION D(NEQ,NL),P(NSS,NL)                                     STO18730
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO18740
      COMMON /STR/ ST(9,16),XM(16),S(16,16),ND,NS,NRP,LM(16)            STO18750
      DO 600 N=1,NUME                                                   STO18760
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      IF(NO.EQ.0)  WRITE(NWRITE,2000)  N, (I,I=1,NS)                    STO18770
      CALL PTAPE(3,NR)                                                  STO18780
      DO 500 L=1,NL                                                     STO18790
      DO 200 I=1,NS                                                     STO18800
      XM(I)=0.0D0                                                       STO18810
      DO 200 J=1,ND                                                     STO18820
      JJ=LM(J)                                                          STO18830
      IF(JJ.LE.0) GO TO 200                                             STO18840
      XM(I)=XM(I)+ST(I,J)*D(JJ,L)                                       STO18850
  200 CONTINUE                                                          STO18860
      IF(NO.EQ.0)  WRITE(NWRITE,2001)  L, (XM(I),I=1,NS)                STO18870
      IF(NSS.EQ.0) GO TO 500                                            STO18880
      M=NS*(N-1)+1                                                      STO18890
      DO 300 I=1,NS                                                     STO18900
      P(M,L)=XM(I)                                                      STO18910
  300 M=M+1                                                             STO18920
  500 CONTINUE                                                          STO18930
  600 CONTINUE                                                          STO18940
      RETURN                                                            STO18950
 2000 FORMAT (12HOFOR ELEMENT I4,/,11H LOAD/FORCE,9(I7,6X))             STO18960
 2001 FORMAT (1H ,I3,7X,9(1PD13.5))                                     STO18970
      END                                                               STO18980
      SUBROUTINE LOADI(L,NR,NC,N3,N4)                                   STO18990
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO19000
      COMMON /TEMP/ FOR(40)                                             STO19010
      DIMENSION L(NR,NC)                                                STO19020
      COMMON /PSIZE/ NO                                                 STO19030
C----- SUBPROGRAM TO LOAD AND PRINT INTEGER ARRAY----                   STO19040
      IF(N3.NE.0) GO TO 100                                             STO19050
      READ(NREAD,1000) ((L(I,J),J=1,NC),I=1,NR)                         STO19060
      GO TO 200                                                         STO19070
  100 READ(NREAD,1001)FOR                                               STO19080
      READ(NREAD,FOR) ((L(I,J),J=1,NC),I=1,NR)                          STO19090
  200 IF(NO.NE.0)  RETURN                                               STO19100
      IF(N4.LT.1 .OR. N4.GT.20)N4=20                                    STO19110
      DO 300 I=1,NC,N4                                                  STO19120
      IH = MINO(I+N4-1,NC)                                              STO19130
      WRITE(NWRITE,2000)  (K,K=I,IH)                                    STO19140
      DO 300 J=1,NR                                                     STO19150
  300 WRITE(NWRITE,2001) (J,(L(J,K),K=I,IH))                            STO19160
      RETURN                                                            STO19170
 1000 FORMAT(16I5)                                                      STO19180
 1001 FORMAT (40A2)                                                     STO19190
 2000 FORMAT (5X,20I5)                                                  STO19200
 2001 FORMAT (21I5)                                                     STO19210
      END                                                               STO19220
      SUBROUTINE DISPL(U,ID,NEQ,NL,NUMNP)                               STO19230
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO19240
      DIMENSION U(NEQ,NL),ID(NUMNP,6)                                   STO19250
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      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                STO19260
      COMMON /TEMP/UU(6)                                                   STO19270
C                                                                          STO19280
      DO 200 N=1,NUMNP                                                     STO19290
      WRITE(NWRITE,2000)                                                   STO19300
      DO 200 L=1,NL                                                        STO19310
      DO 100 I=1,6                                                         STO19320
      UU(I)=0.0D0                                                          STO19330
      II=ID(N,I)                                                           STO19340
      IF(II.LE.0) GO TO 100                                                STO19350
      UU(I)=U(II,L)                                                        STO19360
  100 CONTINUE                                                             STO19370
  200 WRITE(NWRITE,2001)N,L,UU                                             STO19380
      RETURN                                                               STO19390
 2000 FORMAT(12H  NODE  LOAD 13X 2HUX 13X 2HUY 13X 2HUZ 13X 2HTX           STO19400
     1 13X 2HTY 13X 2HTZ )                                                 STO19410
 2001 FORMAT (2I6,6(1PD15.6))                                              STO19420
      END                                                                  STO19430
      SUBROUTINE LOADS(ID,R,NEQ,NL,NUMNP)                                  STO19440
      IMPLICIT REAL*8 (A-H,O-Z)                                            STO19450
      DIMENSION R(NEQ,NL),ID(NUMNP,6)                                      STO19460
      COMMON /TEMP/ RR(6)                                                  STO19470
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                STO19480
      DO 100 N=1,NEQ                                                       STO19490
      DO 100 L=1,NL                                                        STO19500
  100 R(N,L)=0.0D0                                                         STO19510
      IF(NO.EQ.0) WRITE(NWRITE,2000)                                       STO19520
  200 READ(NREAD,1000) N,L,RR                                              STO19530
      IF(N.EQ.0) RETURN                                                    STO19540
      IF(NO.EQ.0) WRITE(NWRITE,2001) N,L,RR                                STO19550
      DO 300 I=1,6                                                         STO19560
      II=ID(N,I)                                                           STO19570
      IF(II.LE.0) GO TO 300                                                STO19580
      R(II,L)=RR(I)                                                        STO19590
  300 CONTINUE                                                             STO19600
      GO TO 200                                                            STO19610
 1000 FORMAT (2I5,6F10.0)                                                  STO19620
 2000 FORMAT (12H  NODE  LOAD  13X 2HFX 13X 2HFY 13X 2HFZ 13X 2HMX         STO19630
     1 13X 2HMY 13X 2HMZ )                                                 STO19640
 2001 FORMAT (2I6,6(1PD15.6))                                              STO19650
      END                                                                  STO19660
      SUBROUTINE NODES(XYZ,NUMNP)                                          STO19670
      IMPLICIT REAL*8 (A-H,O-Z)                                            STO19680
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                STO19690
      DIMENSION XYZ(NUMNP,3)                                               STO19700
C-----READ AND PRINT OF NODAL POINT COORDINATES---                         STO19710
      IF(NO.EQ.0) WRITE(NWRITE,2001)                                       STO19720
  100 READ(NREAD,1000) N,X,Y,Z                                             STO19730
      IF(N.EQ.0) RETURN                                                    STO19740
```

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      XYZ(N,1)=X                                                        STO19750
      XYZ(N,2)=Y                                                        STO19760
      XYZ(N,3)=Z                                                        STO19770
      IF(NO.EQ.0)WRITE(NWRITE,2000) N,XYZ(N,1),XYZ(N,2),XYZ(N,3)        STO19780
      GO TO 100                                                         STO19790
 1000 FORMAT (I5,5X,3F10.0)                                             STO19800
 2001 FORMAT (8HONODE NO  14X,1HX,14X,1HY,14X,1HZ)                      STO19810
 2000 FORMAT(I8,3F15.3)                                                 STO19820
      END                                                               STO19830
      SUBROUTINE BOUND(ID,NUMNP,NEQ)                                    STO19840
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO19850
      DIMENSION ID(NUMNP,6),II(6)                                       STO19860
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE                     STO19870
C-----ZERO ID ARRAY-------------------------------                      STO19880
      DO 100 N=1,NUMNP                                                  STO19890
      DO 100 I=1,6                                                      STO19900
  100 ID(N,I)=0                                                         STO19910
C-----SPECIFICATION OF UNKNOWN DISPLACEMENTS                            STO19920
  200 READ(NREAD,1000)NL,NH1,(II(I),I=1,6),INC                          STO19930
      IF(NL.EQ.0) GO TO 300                                             STO19940
      IF(INC.EQ.0)  INC=1                                               STO19950
      IF(NO.EQ.0)  WRITE(NWRITE,1000)NL,NH1,(II(I),I=1,6),INC           STO19960
      DO 250 J=NL,NH1,INC                                               STO19970
      DO 250 I=1,6                                                      STO19980
  250 ID(J,I)=II(I)                                                     STO19990
      GO TO 200                                                         STO20000
C-----EVALUATION OF EQUATION NUMBERS--------------                      STO20010
  300 NEQ=0                                                             STO20020
      DO 400 N=1,NUMNP                                                  STO20030
      DO 350 I=1,6                                                      STO20040
      IF(ID(N,I).EQ.0) GO TO 350                                        STO20050
      NEQ=NEQ+1                                                         STO20060
      ID(N,I)=NEQ                                                       STO20070
  350 CONTINUE                                                          STO20080
  400 CONTINUE                                                          STO20090
      IF(NO.EQ.0)  WRITE(NWRITE,2000)(N,(ID(N,I),I=1,6),N=1,NUMNP)      STO20100
      RETURN                                                            STO20110
 1000 FORMAT (9I5)                                                      STO20120
 2000 FORMAT(42HOEQUATION NUMBERS FOR NODAL DISPLACEMENTS  /            STO20130
     1 35H NODE     X     Y     Z    XX    YY    ZZ /(7I5))            STO20140
      END                                                               STO20150
      SUBROUTINE GROUP3(LAST,IERR)                                      STO20160
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO20170
      COMMON MTOT,NDF,L(1)                                              STO20180
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO20190
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                       STO20200
      LOGICAL COMP                                                      STO20210
      DIMENSION IOP(3,10)                                               STO20220
      DATA IOP(1,1),IOP(2,1),IOP(3,1) /4HPONG,4H    ,4H    /           STO20230
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      DATA IOP(1,2),IOP(2,2),IOP(3,2) /4HSTEP,4H    ,4H    /          STO20240
      DATA IOP(1,3),IOP(2,3),IOP(3,3) /4HEIGE,4HN   ,4H    /          STO20250
      DATA IOP(1,4),IOP(2,4),IOP(3,4) /4HDYNA,4HM   ,4H    /          STO20260
      DATA IOP(1,5),IOP(2,5),IOP(3,5) /4HPLOT,4H    ,4H    /          STO20270
      NUMOP=5                                                        STO20280
      GO TO 175                                                      STO20290
C---- READ OPERATION FROM CARD OR STORAGE  ----------------          STO20300
  100 CALL INPUT(IERR)                                               STO20310
      IF(IERR .GT. 1) RETURN                                         STO20320
C-----INTERPRETE OPERATION ----------------------                    STO20330
  175 DO 200 J=1,NUMOP                                               STO20340
      N=J                                                            STO20350
      IF (COMP(INHOL(1,1),IOP(1,J))) GO TO 300                       STO20360
  200 CONTINUE                                                       STO20370
      RETURN                                                         STO20380
C-----EXECUTE APPROPRIATE OPERATION --------------                   STO20390
  300 LAST=3                                                         STO20400
      GO TO (1,2,3,4,5),N                                            STO20410
    1 CALL FUNG(IERR)                                                STO20420
      IF(IERR .GT. 1) RETURN                                         STO20430
      GO TO 100                                                      STO20440
    2 CALL STEP(IERR)                                                STO20450
      IF(IERR .GT. 1) RETURN                                         STO20460
      GO TO 100                                                      STO20470
    3 CALL EIGEN(IERR)                                               STO20480
      IF(IERR .GT. 1) RETURN                                         STO20490
      GO TO 100                                                      STO20500
    4 CALL DYNAM(IERR)                                               STO20510
      IF(IERR .GT. 1) RETURN                                         STO20520
      GO TO 100                                                      STO20530
    5 CALL PLOT(IERR)                                                STO20540
      IF(IERR .GT. 1) RETURN                                         STO20550
      GO TO 100                                                      STO20560
      END                                                            STO20570
      SUBROUTINE FUNG(IERR)                                          STO20580
      IMPLICIT REAL*8 (A-H,O-Z)                                      STO20590
      COMMON MTOT,NDP,L(1)                                           STO20600
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR          STO20610
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                    STO20620
      COMMON /ADIR/ NA,I(10)                                         STO20630
      CALL DELETE(INHOL(1,3))                                        STO20640
      IF(N1.LE.0) CALL ERCOM(IERR)                                   STO20650
      IF(IERR .GT. 1) RETURN                                         STO20660
      IF(N2.NE.0) N2=1                                               STO20670
      N2=N2+1                                                        STO20680
      CALL LIST(INHOL(1,3),N2,N1,NDP,IERR)                           STO20690
      N3=NA                                                          STO20700
      CALL FIND(INHOL(1,4),IERR)                                     STO20710
      IF(IERR .GT. 1) RETURN                                         STO20720
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      N4=NA                                                             STO20730
      CALL FIND(INHOL(1,2),IERR)                                        STO20740
      IF(IERR .GT. 1) RETURN                                            STO20750
      IF(I(4).NE.2) CALL ERCOM(IERR)                                    STO20760
      IF(IERR .GT. 1) RETURN                                            STO20770
      CALL FUNGS(L(NA),L(N3),I(3),N1,N2,L(N4))                          STO20780
      RETURN                                                            STO20790
      END                                                               STO20800
      SUBROUTINE FUNGS(G,GG,NC,N1,N2,DT)                                STO20810
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO20820
      DIMENSION G(2,NC),GG(N2,N1)                                       STO20830
      T=G(1,1)                                                          STO20840
      J=1                                                               STO20850
      NCC=NC-1                                                          STO20860
      DO 200 I=1,NCC                                                    STO20870
      S=(G(2,I+1)-G(2,I))/(G(1,I+1)-G(1,I))                             STO20880
  100 GG(1,J)=T                                                         STO20890
      GG(N2,J)=G(2,I)+S*(T-G(1,I))                                      STO20900
      IF(J.EQ.N1) RETURN                                                STO20910
      J=J+1                                                             STO20920
      T=T+DT                                                            STO20930
      IF(T.LT.G(1,I+1)) GO TO 100                                       STO20940
  200 CONTINUE                                                          STO20950
      CALL ERCOM(IERR)                                                  STO20960
      RETURN                                                            STO20970
      END                                                               STO20980
      SUBROUTINE STEP(IERR)                                             STO20990
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO21000
      COMMON MTOT,NDP,L(1)                                              STO21010
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO21020
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                       STO21030
      COMMON /ADIR/ NA,I(10)                                            STO21040
      CALL DELETE(INHOL(1,6))                                           STO21050
      CALL FIND(INHOL(1,2),IERR)                                        STO21060
      IF(I(3).NE.I(4)) CALL ERCOM(IERR)                                 STO21070
      IF(IERR .GT. 1) RETURN                                            STO21080
      NK=NA                                                             STO21090
      N=I(3)                                                            STO21100
      CALL FIND(INHOL(1,3),IERR)                                        STO21110
      IF(I(3).NE.I(4)) CALL ERCOM(IERR)                                 STO21120
      IF(IERR .GT. 1) RETURN                                            STO21130
      NM=NA                                                             STO21140
      CALL FIND(INHOL(1,4),IERR)                                        STO21150
      IF(I(3).NE.I(4)) CALL ERCOM(IERR)                                 STO21160
      IF(IERR .GT. 1) RETURN                                            STO21170
      NC=NA                                                             STO21180
      CALL FIND(INHOL(1,5),IERR)                                        STO21190
      IF(IERR .GT. 1) RETURN                                            STO21200
      NI=NA                                                             STO21210
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      CALL LIST(INHOL(1,6),N,N2,NDP,IERR)                                    STO21220
      IF(IERR .GT. 1) RETURN                                                 STO21230
      NU=NA                                                                  STO21240
      READ(NREAD,1000) DEL,ALP,THE                                           STO21250
      IF(NO.EQ.0) WRITE(NWRITE,2000) DEL,ALP,THE                             STO21260
      CALL FIND(INHOL(1,7),IERR)                                             STO21270
      IF(IERR .GT. 1) RETURN                                                 STO21280
      ND=NA                                                                  STO21290
      CALL FIND(INHOL(1,8),IERR)                                             STO21300
      IF(IERR .GT. 1) RETURN                                                 STO21310
      NF=NA                                                                  STO21320
      CALL FIND(INHOL(1,9),IERR)                                             STO21330
      IF(IERR .GT. 1) RETURN                                                 STO21340
      CALL STEPS(L(NK),L(NM),L(NC),L(NI),L(ND),L(NF),L(NU),N,N1,N2,L(NA)     STO21350
     1,DEL,ALP,THE)                                                          STO21360
      RETURN                                                                 STO21370
 1000 FORMAT(3F10.0)                                                         STO21380
 2000 FORMAT(2X,4HDEL=1PD15.6,3X4HALP=1PD15.6,3X,4HTHE=1PD15.6)              STO21390
      END                                                                    STO21400
      SUBROUTINE STEPS(S,XM,C,UI,D,F,U,N,N1,N2,DTT,DEL,ALP,THE)              STO21410
      IMPLICIT REAL*8 (A-H,O-Z)                                              STO21420
      DIMENSION S(N,N),XM(N,N),C(N,N),UI(N,3),U(N,N2),D(1),F(1)              STO21430
C---- COMPUTE INTEGRATION CONSTANTS----------                                STO21440
      IF(THE.EQ.0.0D0) THE=1.0D0                                             STO21450
      DT=THE*DTT                                                             STO21460
      A0=1.D0/(ALP*DT*DT)                                                    STO21470
      A1=DEL/(ALP*DT)                                                        STO21480
      A2=1.D0/(ALP*DT)                                                       STO21490
      A3=0.5D0/ALP-1.D0                                                      STO21500
      A4=DEL/ALP -1.D0                                                       STO21510
      A5=0.5D0*DT*(DEL/ALP-2.D0)                                             STO21520
      A6=DTT*(1.D0-DEL)                                                      STO21530
      A7=DTT*DEL                                                             STO21540
      A8=(.5D0-ALP)*DTT*DTT                                                  STO21550
      A9=ALP*DTT*DTT                                                         STO21560
C---- FORM AND TRIANGULARIZE EFFECTIVE STIFFNESS MATRIX--------              STO21570
      DO 100 I=1,N                                                           STO21580
      DO 100 J=1,N                                                           STO21590
  100 S(I,J)=S(I,J)+A0*XM(I,J)+A1*C(I,J)                                     STO21600
      CALL SYMSOL(S,UI,N,1,1,0)                                              STO21610
C---- FOR EACH TIME STEP----------------------------                         STO21620
      K=1                                                                    STO21630
      DO 400 I=1,N2                                                          STO21640
      DO 400 J=1,N1                                                          STO21650
C       1. CALCULATE EFFECTIVE LOAD AT TIME T+DT                             STO21660
      K=K+1                                                                  STO21670
      FF=F(K-1)+THE*(F(K)-F(K-1))                                            STO21680
      DO 200 L=1,N                                                           STO21690
  200 U(L,I)=D(L)*FF                                                         STO21700
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      DO 250 L=1,N                                                      STO21710
      X=A0*UI(L,1)+A2*UI(L,2)+A3*UI(L,3)                                STO21720
      Y=A1*UI(L,1)+A4*UI(L,2)+A5*UI(L,3)                                STO21730
      DO 250 M=1,N                                                      STO21740
  250 U(M,I)=U(M,I)+XM(M,L)*X+C(M,L)*Y                                  STO21750
C       2. SOLVE FOR DISPLACEMENT AT T+DT                               STO21760
      CAL. SYMSOL(S,U(1,I),N,1,2,0)                                     STO21770
C       3. CALCULATE ACCELERATIONS AND VELOCITIES AT TIME T+DT          STO21780
      DO 300 L=1,N                                                      STO21790
      A=A0*(U(L,I)-UI(L,1))-A2*UI(L,2)-A3*UI(L,3)                       STO21800
      DA=(A-UI(L,3))/THE                                                STO21810
      A=UI(L,3)+DA                                                      STO21820
      V=UI(L,2)+A6*UI(L,3)+A7*A                                         STO21830
      U(L,I)=UI(L,1)+DTT*UI(L,2)+A8*UI(L,3)+A9*A                        STO21840
      UI(L,3)=A                                                         STO21850
      UI(L,2)=V                                                         STO21860
  300 UI(L,1)=U(L,I)                                                    STO21870
  400 CONTINUE                                                          STO21880
C                                                                       STO21890
      RETURN                                                            STO21900
      END                                                               STO21910
      SUBROUTINE DYNAM(IERR)                                            STO21920
      IMPLICIT REAL*8 (A-H,O-Z)                                         STO21930
      COMMON MTOT,NDP,L(1)                                              STO21940
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR             STO21950
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                       STO21960
      COMMON /ADIR/ NA,I(10)                                            STO21970
C-----SUBROUTINE TO EVALUATE MODAL DYNAMIC RESPONSE--------             STO21980
      CALL DELETE(INHOL(1,6))                                           STO21990
      CALL FIND(INHOL(1,2),IERR)                                        STO22000
      IF(IERR .GT. 1) RETURN                                            STO22010
      N2=NA                                                             STO22020
      N=I(3)*I(4)                                                       STO22030
      CALL FIND(INHOL(1,3),IERR)                                        STO22040
      IF(IERR .GT. 1) RETURN                                            STO22050
      N3=NA                                                             STO22060
      N5=I(3)*I(4)                                                      STO22070
      IF(N.NE.N5) CALL ERCOM(IERR)                                      STO22080
      IF(IERR .GT. 1) RETURN                                            STO22090
      CALL FIND(INHOL(1,4),IERR)                                        STO22100
      IF(IERR .GT. 1) RETURN                                            STO22110
      N4=NA                                                             STO22120
      N5=I(3)*I(4)                                                      STO22130
      IF(N.NE.N5) CALL ERCOM(IERR)                                      STO22140
      IF(IERR .GT. 1) RETURN                                            STO22150
      CALL FIND(INHOL(1,5),IERR)                                        STO22160
      IF(IERR .GT. 1) RETURN                                            STO22170
      N5=NA                                                             STO22180
      CALL FIND(INHOL(1,7),IERR)                                        STO22190
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      IF(IERR .GT. 1) RETURN                                                STO22200
      N6=NA                                                                 STO22210
      CALL LIST(INHOL(1,6),N,N1,NDP,IERR)                                   STO22220
      IF(IERR .GT. 1) RETURN                                                STO22230
      CALL DYNAMS(L(N2),L(N3),L(N4),L(N5),L(NA),N1,N,L(N6))                 STO22240
      RETURN                                                                STO22250
      END                                                                   STO22260
      SUBROUTINE DYNAMS(FQ,DAM,P,PA,X,NTIME,NM,DDT)                         STO22270
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO22280
      DIMENSION FQ(NM),DAM(NM),P(NM),X(NM,NTIME),PA(2,1)                    STO22290
C     EVALUATION OF MODAL RESPONSE ... USING EXPLICIT INTEGRATION           STO22300
      DO 700 M=1,NM                                                         STO22310
      W=FQ(M)                                                               STO22320
      DAMP=DAM(M)                                                           STO22330
      WW=W*W                                                                STO22340
      ZW=DAMP*W                                                             STO22350
      TZW=2.D0*ZW                                                           STO22360
      WD=W*DSQRT(1.0D0-DAMP*DAMP)                                           STO22370
      FB=TZW/(WW*WW)                                                        STO22380
      FA=ZW/WW                                                              STO22390
      FV=ZW*WW                                                              STO22400
      FVD=WW*(2.D0*DAMP*DAMP-1.0D0)                                         STO22410
      FBB=(2.D0*DAMP*DAMP-1.0D0)/WW                                         STO22420
      L=0                                                                   STO22430
      II=1                                                                  STO22440
      VO=0.D0                                                               STO22450
      VDO=0.D0                                                              STO22460
      TO=PA(1,1)                                                            STO22470
C                                                                           STO22480
   10 DT=DDT                                                                STO22490
   50 B=(PA(2,II+1)-PA(2,II))/(PA(1,II+1)-PA(1,II))                         STO22500
      B=B*P(M)                                                              STO22510
      A=P(M)*PA(2,II)+B*(TO-PA(1,II))                                       STO22520
      TT=TO+DT                                                              STO22530
      IF(PA(1,II+1).GT.TT) GO TO 100                                        STO22540
      DELT=PA(1,II+1)-TO                                                    STO22550
      GO TO 200                                                             STO22560
  100 DELT=DT                                                               STO22570
C                                                                           STO22580
  200 EX=DEXP(-ZW*DELT)                                                     STO22590
      PT=WD*DELT                                                            STO22600
      CS=DCOS(PT)                                                           STO22610
      SN=DSIN(PT)                                                           STO22620
      VT=(VDO+ZW*VO-FA*A+FBB*B)*SN/WD                                       STO22630
      VT=VT+(VO-A/WW+FB*B)*CS                                               STO22640
      VT=VT*EX+A/WW-FB*B+B*DELT/WW                                          STO22650
      VDT=(A-WW*VO-ZW*(VDO+B/WW))*SN/WD                                     STO22660
      VDT=EX*((VDO-B/WW)*CS+VDT)+B/WW                                       STO22670
      VDDT=(B+FV*VO+FVD*VDO-ZW*A)/WD                                        STO22680
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      VDDT=EX*((A-WW*VO-TZW*VDO)*CS+VDDT*SN)                                    STO22690
      VO=VT                                                                     STO22700
      VDO=VDT                                                                   STO22710
C                                                                               STO22720
      IF(PA(1,II+1).GT.TT) GO TO 500                                            STO22730
      DT=DT-DELT                                                                STO22740
      II=II+1                                                                   STO22750
      TO=PA(1,II)                                                               STO22760
      IF(DT.EQ.0.D0) GO TO 600                                                  STO22770
      GO TO 50                                                                  STO22780
  500 TO=TO+DT                                                                  STO22790
  600 L=L+1                                                                     STO22800
      X(M,L)=VT                                                                 STO22810
      IF(L.LT.NTIME) GO TO 10                                                   STO22820
  700 CONTINUE                                                                  STO22830
C                                                                               STO22840
      RETURN                                                                    STO22850
      END                                                                       STO22860
      SUBROUTINE EIGEN(IERR)                                                    STO22870
      IMPLICIT REAL*8 (A-H,O-Z)                                                 STO22880
      COMMON MTOT,NDP,L(1)                                                      STO22890
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                     STO22900
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                               STO22910
      COMMON /ADIR/ NA,I(10)                                                    STO22920
      CALL DELETE(INHOL(1,3))                                                   STO22930
      CALL FIND(INHOL(1,2),IERR)                                                STO22940
      IF(I(3).NE.I(4)) CALL ERCOM(IERR)                                         STO22950
      IF(IERR .GT. 1) RETURN                                                    STO22960
      N2=I(4)                                                                   STO22970
      N3=NA                                                                     STO22980
      CALL FIND(INHOL(1,4),IERR)                                                STO22990
      IF(I(1).NE.N2) CALL ERCOM(IERR)                                           STO23000
      IF(IERR .GT. 1) RETURN                                                    STO23010
      N4=NA                                                                     STO23020
      CALL LIST(INHOL(1,3),N2,N2,NDP,IERR)                                      STO23030
      IF(IERR .GT. 1) RETURN                                                    STO23040
      CALL EIGENS(L(N3),L(NA),L(N4),N2,N1,N3)                                   STO23050
      IF(NO.EQ.0) WRITE(NWRITE,2000) N1,N3                                      STO23060
      RETURN                                                                    STO23070
 2000 FORMAT(I3,27H FIGURE TOLERANCE SPECIFIED  / I6,                           STO23080
     1 20H ROTATIONS PERFORMED )                                                STO23090
      END                                                                       STO23100
      SUBROUTINE EIGENS(H,O,E,N,NS,NR)                                          STO23110
      IMPLICIT REAL*8 (A-H,O-Z)                                                 STO23120
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                     STO23130
      DIMENSION H(N,1),O(N,1),E(N)                                              STO23140
C                                                                               STO23150
      IF(NS.EQ.0) NS=4                                                          STO23160
      TEST=1.0D0/10.D0**(2*NS)                                                  STO23170
```

```
      NN=N-1                                                            STO23180
      NR=0                                                              STO23190
      NRLM=5*N*N                                                        STO23200
      TOLER=0.1D0                                                       STO23210
      ZERO = 0.0D0                                                      STO23220
C-----NORMALIZE TO UNIT MATRIX--------------------                      STO23230
      DO 10 I=1,N                                                       STO23240
   10 E(I)=1.0D0/DSQRT(E(I))                                            STO23250
      DO 30 I=1,N                                                       STO23260
      DO 20 J=1,N                                                       STO23270
      H(I,J)=E(I)*H(I,J)*E(J)                                           STO23280
   20 U(I,J)=0.0D0                                                      STO23290
      ZERO = ZERO + DABS(H(I,I))                                        STO23300
   30 U(I,I)=1.0D0                                                      STO23310
      ZERO = ZERO*1.0D-16                                               STO23320
C---- REDUCE MATRIX -------------------------------                     STO23330
   50 XMAX=0.0D0                                                        STO23340
      DO 700 II=1,NN                                                    STO23350
      JL=II+1                                                           STO23360
      DO 600 JJ=JL,N                                                    STO23370
C-----CHECK IF ROTATION IS REQUIRED   ------------                      STO23380
      HII=H(II,II)                                                      STO23390
      HIJ=H(II,JJ)                                                      STO23400
      HJJ=H(JJ,JJ)                                                      STO23410
      D=DABS(HII*HJJ)                                                   STO23420
      H2=HIJ*HIJ                                                        STO23430
      IF(H2.GT.XMAX*D) XMAX=H2/D                                        STO23440
      IF(H2.LT.TOLER*D) GO TO 600                                       STO23450
C-----COMPUTE TAN, SIN AND COS --------------------                     STO23460
      NR=NR+1                                                           STO23470
      IF(DABS(HIJ) - ZERO)300,300,320                                   STO23480
  300 CS = 0.0D0                                                        STO23490
      SN = 1.0D0                                                        STO23500
      GO TO 350                                                         STO23510
  320 HT=.5D0*(HII-HJJ)/HIJ                                             STO23520
      TN=-HT-DSIGN(DSQRT(HT*HT+1.0D0),HT)                               STO23530
      CS =1.0D0/DSQRT(1.D0+TN *TN)                                      STO23540
      SN=CS*TN                                                          STO23550
  350 C2=CS*CS                                                          STO23560
      S2=SN*SN                                                          STO23570
C-----REDUCE II,JJ ELEMENT TO ZERO ----------------                     STO23580
      HT=2.D0*HIJ*CS*SN                                                 STO23590
      H(II,JJ)=0.0D0                                                    STO23600
      H(II,II)=HII*C2+HT+HJJ*S2                                         STO23610
      H(JJ,JJ)=HII*S2-HT+HJJ*C2                                         STO23620
      DO 530 I=1,N                                                      STO23630
      IF(I-II) 370,530,420                                              STO23640
  370 HT=H(I,II)                                                        STO23650
      H(I,II)=CS *HT+SN *H(I,JJ)                                        STO23660
```

```
      H(I,JJ)=-SN*HT+CS*H(I,JJ)                                          STO23670
      GO TO 530                                                          STO23680
  420 IF(I-JJ) 430,530,480                                               STO23690
  430 HT=H(II,I)                                                         STO23700
      H(II,I)=CS*HT+SN*H(I,JJ)                                           STO23710
      H(I,JJ)=-SN*HT+CS*H(I,JJ)                                          STO23720
      GO TO 530                                                          STO23730
  480 HT=H(II,I)                                                         STO23740
      H(II,I)=CS*HT+SN*H(JJ,I)                                           STO23750
      H(JJ,I)=-SN*HT+CS*H(JJ,I)                                          STO23760
  530 CONTINUE                                                           STO23770
C-----OPERATE ON EIGENVECTORS --------------------                       STO23780
  540 DO 550 I=1,N                                                       STO23790
      HT=J(I,II)                                                         STO23800
      U(I,II)=CS*HT+SN*U(I,JJ)                                           STO23810
  550 U(I,JJ)=-SN*HT+CS*U(I,JJ)                                          STO23820
  600 CONTINUE                                                           STO23830
  700 CONTINUE                                                           STO23840
C-----TEST FOR END OF ITERATION AND SET NEW TOLERANCE                    STO23850
      IF(NRLM.LT.NR) GO TO 1000                                          STO23860
      IF(XMAX.LE.TEST) GO TO 710                                         STO23870
      TOLER=0.10D0*XMAX                                                  STO23880
      GO TO 50                                                           STO23890
C-----NORMALIZE AND ORDER EIGENVECTORS -----------                       STO23900
  710 DO 800 I=1,N                                                       STO23910
      DO 750 J=1,N                                                       STO23920
  750 U(I,J)=U(I,J)*E(I)                                                 STO23930
  800 E(I)=H(I,I)                                                        STO23940
      DO 900 I=1,NN                                                      STO23950
C-----ORDER EIGENVALUES AND EIGENVECTORS ---------                       STO23960
      JL=I+1                                                             STO23970
      HT=E(I)                                                            STO23980
      IM=I                                                               STO23990
      DO 850 J=JL,N                                                      STO24000
      IF(HT.LT.E(J)) GO TO 850                                           STO24010
      HT=E(J)                                                            STO24020
      IM=J                                                               STO24030
  850 CONTINUE                                                           STO24040
      E(IM)=E(I)                                                         STO24050
      E(I)=HT                                                            STO24060
      DO 900 J=1,N                                                       STO24070
      HT=J(J,I)                                                          STO24080
      U(J,I)=U(J,IM)                                                     STO24090
  900 U(J,IM)=HT                                                         STO24100
      RETURN                                                             STO24110
C                                                                        STO24120
 1000 WRITE(NWRITE,2000)                                                 STO24130
      RETURN                                                             STO24140
 2000 FORMAT(41HOITERATION TERMINATED WITHOUT CONVERGENCE )              STO24150
```

```
      END                                                                   STO24160
      SUBROUTINE PLOT(IERR)                                                 STO24170
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO24180
      COMMON MTOT,NDP,L(1)                                                  STO24190
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO24200
      COMMON /CARD/ INHOL(3,10),N1,N2,N3,N4,S1,S2                           STO24210
      COMMON /ADIR/ NA,I(10)                                                STO24220
      DIMENSION IPLOT(3)                                                    STO24230
      DATA IPLOT /4HPLOT,4HNM  ,4H   /                                      STO24240
      NT=121+N1+N1                                                          STO24250
      CALL LIST(IPLOT,1,NT,NSP,IERR)                                        STO24260
      IF(IERR .GT. 1) RETURN                                                STO24270
      NP=NA                                                                 STO24280
      NK=NA+121                                                             STO24290
      NN=NK+N1                                                              STO24300
      CALL FIND(INHOL(1,2),IERR)                                            STO24310
      IF(IERR .GT. 1) RETURN                                                STO24320
      CALL PLOTS(L(NA),L(NP),L(NK),L(NN),I(4),I(3),N1)                      STO24330
      CALL DELETE(IPLOT)                                                    STO24340
      RETURN                                                                STO24350
      END                                                                   STO24360
      SUBROUTINE PLOTS(A,K,KODE,NROW,NR,NC,N1)                              STO24370
      IMPLICIT REAL*8 (A-H,O-Z)                                             STO24380
      COMMON /PSIZE/ NO,NARA,NSIZE,NSP,NREAD,NWRITE,NH,NDIR                 STO24390
      DIMENSION A(NR,NC),K(121),KODE(N1),NROW(N1)                           STO24400
C---- SUBROUTINE TO PRINTER PLOT N1 ROWS OF ARRAY A                         STO24410
      DATA INDIA /2HI /,IBLANK /2H  /,IZERO /2H0 /                          STO24420
      READ(NREAD,1000) (KODE(I),NROW(I),I=1,N1)                             STO24430
      IF(NO.NE.0) RETURN                                                    STO24440
      WRITE(NWRITE,2000) (KODE(I),NROW(I),I=1,N1)                           STO24450
C----- LOCATE LARGEST AND SMALLEST ELEMENTS-------                          STO24460
      II=NROW(1)                                                            STO24470
      AL=A(II,1)                                                            STO24480
      AS=AL                                                                 STO24490
      DO 100 I=1,N1                                                         STO24500
      II=NROW(I)                                                            STO24510
      DO 100 J=1,NC                                                         STO24520
      AX=A(II,J)                                                            STO24530
      IF(AX.GT.AL) AL=AX                                                    STO24540
      IF(AX.LT.AS) AS=AX                                                    STO24550
  100 CONTINUE                                                              STO24560
      AX=(AL-AS)/120.D0                                                     STO24570
      WRITE(NWRITE,2001)AX,AS,AL                                            STO24580
      KO=-AS/AX +1.D0                                                       STO24590
      DO 300 I=1,NC                                                         STO24600
C---- FILL LINE BUFFER WITH BLANKS AND CODES---                            STO24610
      DO 300 J=1,121                                                        STO24620
  300 K(J)=IBLANK                                                           STO24630
      K(1)=INDIA                                                            STO24640
```

```
      K(121)=INDIA                                                                  STO24650
      IF(K0.GT.0) K(K0)=IZERO                                                       STO24660
      DO 400 J=1,N1                                                                 STO24670
      JJ=NROW(J)                                                                    STO24680
      II=(A(JJ,I)-AS)/AX+1.D0                                                       STO24690
  400 K(II)=KODE(J)                                                                 STO24700
  500 WRITE(NWRITE,2003)K                                                           STO24710
      WRITE(NWRITE,2004)                                                            STO24720
      RETURN                                                                        STO24730
 1000 FORMAT (1A1,I4)                                                               STO24740
 2000 FORMAT (11HOSYMBOL ROW /(5X,1A1,I5))                                          STO24750
 2001 FORMAT (11H ONE SPACE= 1PD15.6/9HOMINIMUM= 1PD15.6,74X 9HMAXIMUM=             STO24760
     1 1PD15.6/  122(1H0))                                                          STO24770
 2003 FORMAT(1H ,121A1)                                                             STO24780
 2004 FORMAT(122(1H0))                                                              STO24790
      END                                                                           STO24800
```

APPENDIX B - USER'S MANUAL

This appendix provides details on use of CAL with the IBM 360/67 computer at NPS. Section I provides details on the command structure. Section II is a summary of commands available. Section III provides the job control language for executing the program in both the batch and interactive modes at NPS. Section IV contains detailed specifications for each available command. Finally, section V gives direction for solving larger problems with CAL. The majority of this appendix was originally published as reference (3). The author wishes to express appreciation to Professor Wilson for permission to use this material.

I. FORM AND RESTRICTION OF THE LANGUAGE

CAL is an interpretive language which is designed to manipulate arrays and matrices and to perform several standard structural analysis operations. A CAL program run involves the reading of the input deck once and executing the commands designated by the operation cards as they are encountered. Looping operations allow a sequence of commands to be executed more than once.

The input deck is composed of operation cards and data cards. The data cards directly follow each operation card which requires data (see LOOP operation for exception to this). The operation card contains the name of the operation to be executed, names of arrays associated with the operation and integer constants. Examples of the general form of this card are

```
OP,M1,M2,M3,M4,M5,N1,N2,N3,N4  COMMENTS
OP,M1,N1,N2
OP,N1
OP
```

in which OP is the name of the operation to be executed, Mi is the name of an array and Ni is an integer. The names of OP or Mi are one to eight alphabetic or numeric characters to be selected by the user. The first character of a name must be alphabetic. The sequence of terms OP,Mi and Ni must be separated by commas. Characters following a blank will be printed as comments in the output from the program run.

If an operation attempts to load or generate an array which previously existed the program will delete the array before the execution of the operation. A new array need not be the same size of the old array which had the same name.

II. SUMMARY OF COMMANDS

A. GENERAL COMMANDS

* indicates a significant change or addition in CAL-NPS

START	- Initialize for the next problem	
STOP	- Normal termination	
NO	- Temporary suppression of output	
YES	- Restores output	
LABEL	- Print comments	
READ	- Change logical device for input	*
WRITE	- Change logical device for output	*
TIME	- Suppress time printout	*
SAVE	- Interrupt a problem	*
RESUME	- Continue an interrupted problem	*
LIST	- List arrays and storage used	*

B. GENERAL MATRIX COMMANDS

LOAD	- Load user defined matrix	
ZERO	- Create null or unit matrix	
PRINT	- Matrix print operation	*
DUP	- Matrix duplication	
ADD	- Matrix addition	
SUB	- Matrix subtraction	
MULT	- Matrix multiplication	
TRAN	- Matrix transpose	
SCALE	- Multiply a matrix by a scalar	
SOLVE	- Solution of linear equations	*
DUPSM	- Form sub-matrix from large matrix	
STOSM	- Store sub-matrix in large matrix	
DUPDG	- Form row matrix from diagonal	

STODG - Store row on diagonal
MAX - Evaluate row maximums
NORM - Evaluate matrix norms
INVEL - Inverte each term in matrix
SQREL - Square root of each term in matrix
LOG - Natural log of each term in matrix
PROD - Evaluate product of all terms in matrix
DELETE - Delete matrix from storage

C. STATIC ANALYSIS OPERATIONS

NODES - Input joint geometry
BOUND - Specify boundary conditions
BEAM - Form 3-D beam stiffness matrix
TRUSS - Form 3-D truss stiffness matrix
PLANE - Form 3 to 8 node plane stiffness matrix
SLOPE - Form stiffness matrix from slope/deflection eq.
FRAME - Form 2-D frame stiffness matrix
LOADI - Load integer array (connectivity matrix) *
LOADS - Form load vector
ADDSF - Form global stiffness and mass matrices
ADDK - Add element matrix to global matrix
MEMFRC - Calculate element forces from joint displacements
DISPL - Print joint displacements
FORCE - Evaluate and print member forces

D. DYNAMIC ANALYSIS OPERATIONS

FUNG - Generate equal interval time function
STEP - Integrate dynamic equilibrium equations
EIGEN - Evaluate mode shapes and frequencies
DYNAM - Evaluate uncoupled equations of motion by mode superposition method
PLOT - Line printer plot of joint time history

E. LOOP OPERATIONS

LOOP - Start of loop
NEXT - End of loop
SKIP - Conditional skip of operations within loop

F. NAMES AVAILABLE FOR USER SUBROUTINES

USERA
USERB

III. JCL FOR EXECUTION

The ibb control language (JCL) necessary to initiate program execution for the OS/MVT (batch) system is:

```
//(standard green job card)
//  EXEC  CAL
//SYSIN DD *


CAL  COMMANDS AND DATA CARDS


/*
```

For the CP/CMS (time-sharing) system the procedure is:

```
use standard login procedure, then
CP LINK 0099P 191 199 PASS= ESAN
LOGIN 199 A,P
CAL


CAL  COMMANDS AND DATA CARDS
```

The following information is provided for the user who wishes to use his own subroutine or solve larger problems then allowed with the default core allocation. The load module library for the OS/MVT operating system is in partitioned data set F0099.CAL on DISK02. The load module is assigned member name MODULE. The file used as a scratch

pad is FT01F001. File FT02F001 is used as the scratch file for the SAVE and RESUME operations. The FT01F001 file is currently pointed at the SYSDA disk and FT02F001 is pointed at dummy. If for any reason a user desires to use the SAVE operation with the OS/MVT system, both FT01F001 and FT02F001 must be redifined. See Computer Center TN No. 0141-05, USER LIBRARIES AND SOURCE CODE EDITING UNDER OS for procedures. File FT01F001 requires 3404 bytes of storage per element. File FT02F001 requires a total of 4 times the dimension of the L array plus 8 bytes and should have RECFM=VBS.

For CP/CMS, the execution routine is

```
&TYPEOUT OFF
CP SET LINELN 130
GLOBAL T SYSLIB SSPLIB
FILEDEF 01  DSK-P4 FILE  FT01F001 RECFM  VS LRECL  3408
BLKSIZE 3412
FILEDEF 02  DSK-P4 FILE  FT02F001 RECFM  VS LRECL  7290
BLKSIZE 7294
FILEDEF 04 DSK
FILEDEF 08 PRT RECFM FBA LRECL 133 (PERM)
LOAD STORE USER CALH (CLEAR NOMAP XEQ)
```

FT01F001 is the scratch pad for the structural analysis. FT02F001 is created by the SAVE operation. Both FT01F001 and FT02F001 must be available for the RESUME operation.

Temporary additional storage can be obtained, if needed, by typing GETTEMP while in CMS. The GETTEMP execution routine is:

```
&TYPEOUT OFF
VSET RDYMSG OFF
CP SET LINELN 130
&BEGSTACK
VSET BLIP +
```

```
CP DEFINE T2314 192 4
FORMAT T ALL (NOTYPE)
RELEASE 192 T
LOGIN 192 P
LOGIN 191 B,P
&ENDSTACK
```

IV. CAL COMMAND SPECIFICATIONS

A. GENERAL MATRIX OPERATIONS

CAL has most of the standard matrix operations plus some special array operations which are useful in structural analysis. The following is a list of approximately 25 operations which are used for control and general matrix manipulation.

\+ indicates the formation of a new matrix. A matrix previously defined with the same name will be deleted.

\- indicates modification of an existing matrix.

START

This operation eliminates all arrays which were perviously loaded or generated.

STOP

This operation causes normal termination of a CAL program.

NO
YES

These operations are used to selectively suppress output from CAL. The NO operations suppresses all printing, except diagnostics, until the operation YES is encountered. Therefore, in subsequent runs of the same CAL program, output which was previously correct need not be reprinted if these cards are inserted in the data deck.

LABEL,N1

This operation will read and print N1 comment cards which follow this operation card. Column 1 of each card will be interpreted as a standard carriage control symbol (i.e. 0 for double space and 1 for skip to the top of the next page).

READ,N1

THIS OPERATION IS VALID ONLY WITH THE CP/CMS TIME SHARING SYSTEM.
This operation permits the selection of the offline printer or the terminal as the input file device. Default is the terminal. N1 = 4 will read subsequent commands from FILE FT04F001 on the users p-disk. N1 = 5 will restore the terminal as the input file device. All disk files prepared for use with this command should end with either STOP or READ,4. This command will not be executed on the OS/MVT (batch) system.

WRITE,N1

THIS OPERATION IS VALID ONLY WITH THE CP/CMS TIME SHARING SYSTEM.
This operation permits the selection of the offline printer or the terminal as the output file device. Default is the terminal and all error messages will be printed at the terminal regardless of the output file device selected. N1 = 3 selects the offline printer. N1 = 6 restores the terminal as the output file device. This command will not be executed on the OS/MVT (batch) system.

TIME

This operation permits the time printout to be suppressed without loss of other output. A second TIME will restore the time printout unless the print output is suppressed with the NO command.

SAVE

The SAVE command creates FILE FT02F001 containing all arrays in storage at the time of issuance. Note that saved arrays will contain any modification since creation. For instance, if a matrix has been reduced by the SOLVE operation, the reduced form of the matrix will be stowed in FILE FT02F001. Note the requirements discussed previously for use of this command with the OS system.

RESUME

The RESUME operation reads FILE FT02F001 into memory. Any arrays currently in storage will be destroyed. FILE FT02F001 must have previously been created on a mass storage device using the SAVE operation. Note that FILE FT01F001 must also be accessible if an interrupted structural analysis problem is being resumed.

LIST

The LIST operation prints the directory information for arrays in storage and the amount of storage used.

+
LOAD,M1,N1,N2,N3

This operation will load an array of real numbers named M1 which has N1 rows and N2 columns. The terms of the array are punched in row-wise sequence on data cards following this operation. If N3 is zero or blank, the cards are punched in a format of (8F10.0). If N3 is nonzero, an additional card containing the format of the data cards must follow this operation and preceed the data cards. If the data is to be 4 numbers per card in field widths of 15, the additional cards would contain the following information: (4F15.0).

+
ZERO,M1,N1,N2,N3,N4

A real matrix named M1 is created with N1 rows and N2 columns. The terms in this matrix will have the following values.

M1(I,I) = N3 I = 1,...N1
M1(I,J) = N4 J = 1,...N2

Therefore, this operation can be used to form null or unit matrices.

PRINT,M1 or PRINT,M1,N1 or PRINT,M1,N1,N2 or PRINT,M1,,N2

This operation will print the real array named M1 in a matrix format of up to 8 columns per line. If N1 is greated than zero the operation will read and print N1 comment cards wich follow the operation card. N2 is optional but note that an extra comma must be used in place of N1 if no printed title is desired. The matrix M1 will be printed in partitioned form with N2 columns per partition. Lines will have N1*15+5 characters. N2 defaults to 8, printing 125 characters per line. The user is cautioned not to overcome the capacity of the printing device in use.

+
DUP,M1,M2

This operation will form an array named M2 which is identical to the array named M1.

-
ADD,M1,M2

This operation will replace matrix M1 with the sum of the matrices M1 and M2.

-
SUB,M1,M2

This operation will replace matrix M1 with matrix M1 less matrix M2.

MULT,M1,M2,M3

This operation generates a new matrix M3 which is the product of matrices M1 and M2, or M3 = M1*M2.

TRAN,M1,M2

This operation generates a new matrix M2 which is the transpose of matrix M1.

SCALE,M1,M2

This operation replaces each term in the matrix named M1 with the term multiplied by the term M2(1,1) of the matrix named M2.

SOLVE,M1,M2,N1,N2 or SOLVE,M1,M2,,N2 or SOLVE,M1,N1,N2 or
SOLVE,M1,M2,N1 or SOLVE,M1,M2 or SOLVE,M1

If N1 = 0, this operation solves the matrix equation AX=B. M1 is the name of the A matrix and M2 is the name of the B matrix. Matrix A is trangularized and the results X, are stored in M2.
If N1=1 Matrix A is triangularized only.
N1=2 For a given B matrix and the A matrix previously triangularized, the B matrix is replaced by the results X.
N1=3 Matrix A is replaced by its inverse FOR SYMMETRIX MATRICES ONLY.
N2=0 or blank, matrix A is symmetric. If N2 is nonzero the matrix A is not symmetric.
For symmetric matrices, matrix A is factored into the LDL form. The diagonal D matrix is stored on the diagonal of A. The parameter N2 permits the direct solution of non-symmetric systems of equations. If N2 is not equal to 0, an LU decomposition of matrix A will be performed. No direct replacement of M1 by its inverse is availabe for the non-symmetric case. Instead, use the ZERO operation to create an identity matrix M2 of the same order as M1. The command SOLVE,M1,M2,,N2 will then replace the matrix M2 with the inverse of the matrix A.

DUPSM,M1,M2,N1,N2,N3,N4

This operation forms a new submatrix named M2 with N3 rows and N4 columns from terms within the matrix named M1. The first term of matrix M2, M2(1,1), will be from row N1 and column N2 of matrix M1, or M1(N1,N2).

STOSM,M1,M2,N1,N2

This operation stores a submatrix named M2 within the matrix named M1. The first term of the submatrix M2 will be stored at row N1 and column N2 of matrix M1. The terms within the area of M1 in which M2 is stored will be destroyed.

DUPDG,M1,M2

This operation forms a new row matrix named M2 from the diagonal terms of matrix M1.

STODG,M1,M2

This operation stores a row or column matrix named M2 at the diagonal locations of matrix M1.

MAX,M1,M2

This operation forms a column matrix named M2 in which each row contains the maximum absolute value of the corresponding row in matrix M1. The maximum and its column number is printed for each row.

NORM,M1,M2,N1

If N1 = 0, a row matrix named M2 is formed in which each column contains the sum of the absolute values of the corresponding column of matrix M1. If N1 /= 0, a row matrix named M2 is formed in which each column contains the square root of the sum of the squares of the values of the corresponding columns of matrix M1.

INVEL,M1

This operation replaces each term in the matrix named M1 with it's inverse.

SQREL,M1

This operation replaces each term in the matrix named M1 with the square root of the term.

LOG,M1

This operation replaces each term in the matrix named M1 with the natural log of the term.

PROD,M1,M2

This operation forms a 1 x 2 array named M2 which contains the product of all terms in the matrix M1. The product, X, is stored as two numbers of the form

X = P*10**E

in which M2(1) = P and M2(2) = E, the exponent.

DELETE,M1

This operation will cause the elimination from storage of the array named M1.

B. STATIC ANALYSIS OPERATIONS

The purpose of this series of operations is to form the total stiffness and diagonal (lumped) mass matrices for systems of two or three-dimensional elements. For three-edimensional analysis, there are beam and truss elements available. For two-dimensional analysis, there is a frame element, a slope/deflection element for beams, and a 3 to 8 node isoparametric finite element available.

After the creation of an array containing the coordinates of the joints of the system, the specification of displacement boundary conditions, the tabulation of material and section properties, the mass and stiffness matrices are formed for each structural member and placed in sequence on low speed storage along with the global equation numbers which are associated with their stiffness terms. In addition, the member force-displacement transformation matrices are formed and stored on a separate low speed storage file along with the appropriate displacement numbers.

The NODES operation is used to specify or generate the geometry of the system. The operation BOUND specifies which joint displacements exists and assigns internal equation numbers to these displacements. Therefore, each joint may have from zero to six displacement degrees of freedom. Tables of material and section properties for the various members are loaded and printed as standard arrays of information.

A special operation, ADDSF, is used for the direct addition of element stiffnesses to form the total stiffness and diagonal mass matrix of the system. The ADDK operation may be used to add individual elements into the total system

matrices. The LOADS operation specifies the concentrated joint loads for all load conditions. After the direct solution for joint displacements due to static or dynamic loads, the member forces can be evaluated useng the FORCE operation. Individual member forces can be evaluated using the MEMFRC operation. The DISPL operation is used to print the displacements in joint number order.

NODES,M1,N1

The cards following this operation provide information for the creation of a N1 by 3 array which will contain the coordinates for all the joints in the system. Where

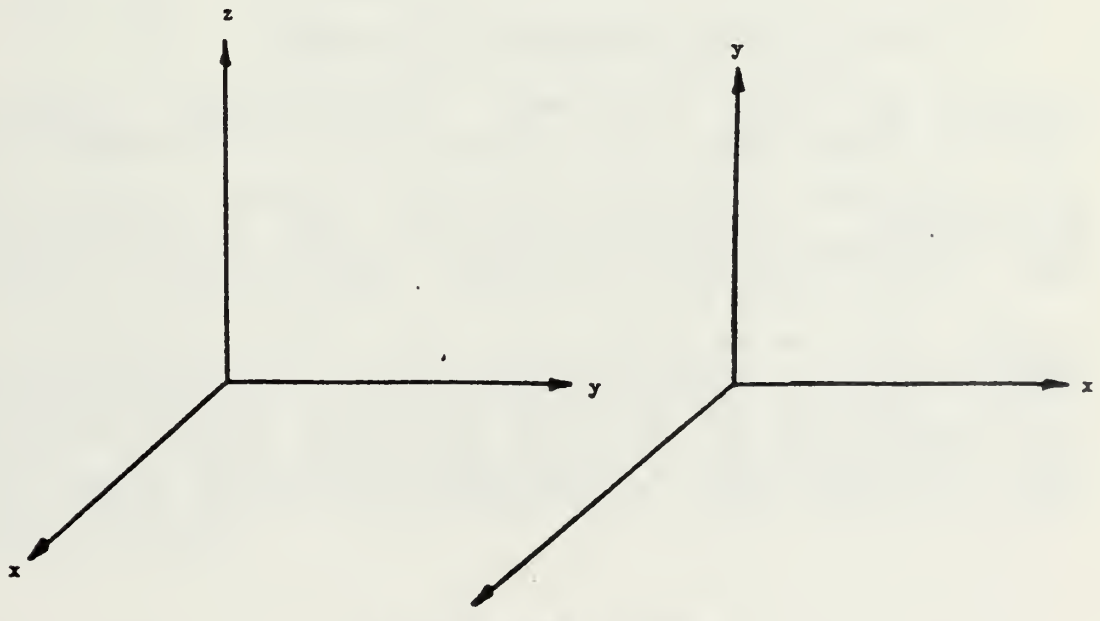
M1 = Name of new coordinate array to be loaded.

N1 = Number of joints (or nodes) in the system.

The following sequence of cards punched in a (2I5,3F10.0) format must follow this operation.

Columns	Contain
1 - 5	Node number selected by user
6 - 10	blank
11 - 20	X-coordinate
21 - 30	Y-coordinate
31 - 40	Z-coordinate

Nodes cards may be supplied in any order; however, all nodes must be defined. If nodes are defined more than once the last definintion will be used. This sequence of data must be terminated with a blank card.



POSITIVE COORDINATE SYSTEMS

BOUND,M1

This operation specifies the displacements which are nonzero for the structural system of joints specified by the NODES operation. Where

M1 = Name of boundary condition cade array to be generated.

This operation is followed by a series of cards containing the following information punched in a (8I5) format.

Columns	Contents
1 - 5	Node number for the first node in a series of nodes with identical displacement specification.
6 - 10	Node number for the last node in the series.
11 - 15	X-translation.
16 - 20	Y-translation
21 - 25	Z-translation
26 - 30	X-rotation
31 - 35	Y-rotation
36 - 40	Z-rotation
41 - 45	Node number increment used to generate Conditions for additional nodes.

A translation or rotation equals: (a) zero for zero or undifined displacements, or (b) one for nonzero displacements to be evaluated by other operations.

If a node boundary condition is not specified, all displacements at that node are assumed zero. Cards may be supplied in any order. If node boundary conditions are specified more than once, the last difinition is used. This sequence of data must be terminated by a blank card.

The selection by the user of which nodes have nonzero displacements requires an understanding of the direct stiffness procedure. Displacements degrees of freedom which have no stiffness associated with the displacement must be considered to be undifined since it is not possible to develop an equilibrium equation for that direction. The total number of nonzero displacements specified will be the size of the total stiffness matrix to be defined by the ADDSF operation.

+
BEAM,M1,M2,M3,M4

This operation calculates the element stiffness, mass and force-displacement transformation matrices for 3-D beam members. These arrays are stored in sequence on low speed storage to be used by other operations where:

M1 is the name of the beam element group
M2 is the name of the coordinate array
M3 is the name of the boundary condition array
M4 is the name of the arra which contain beam properties and has been loaded by the standard matrix LOAD operation

One card for each beam in this group of beam elements must follow this operation. The beam cards are punched in (5I5) format, where

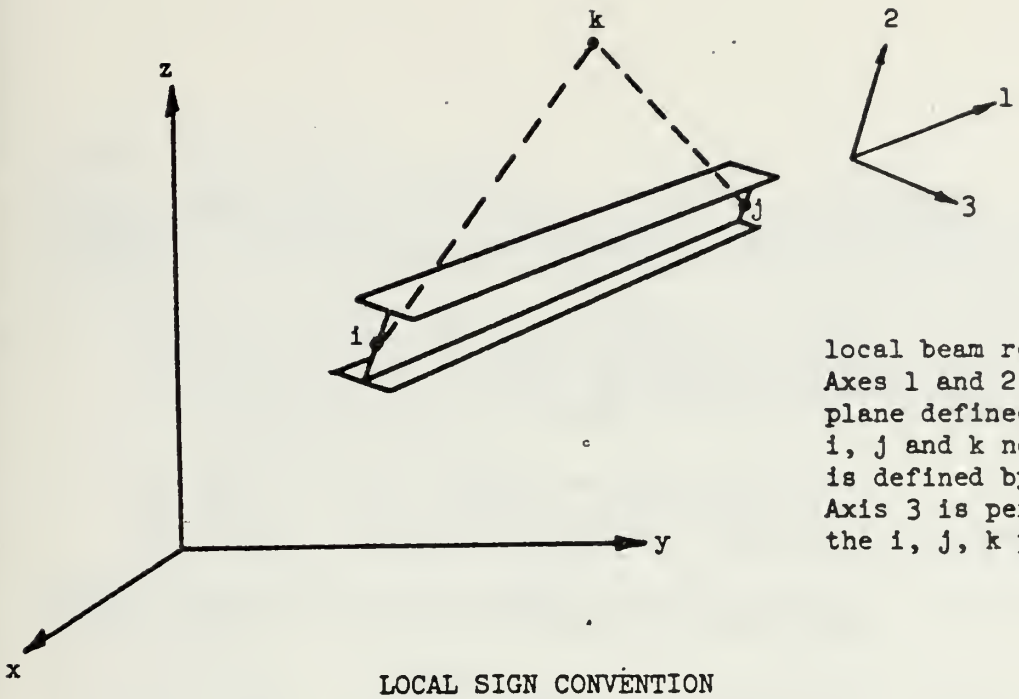
Columns	Contain
1 - 5	Beam identification number
6 - 10	Node number I
11 - 15	Node number J
16 - 20	Node number K
21 - 25	Beam property number NP

This sequence of cards must be terminated with a blank card.

The material and geometric properties for each element are give in the M4 array in the following order:

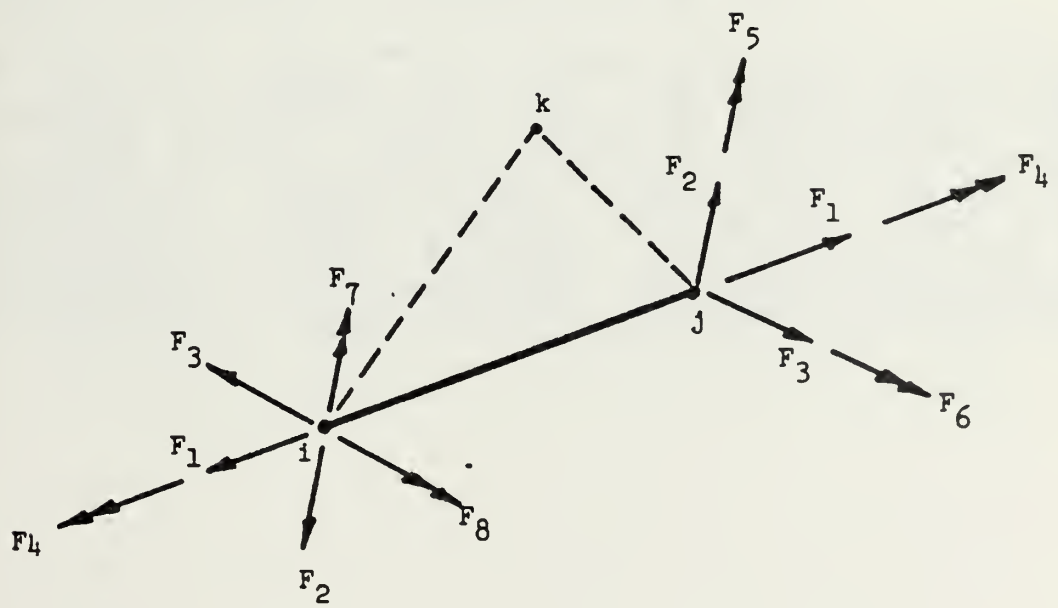
M4(NP,1) = Axial area of member, A
M4(NP,2) = Torsional Moment of Inertia, J
M4(NP,3) = Moment of Inertia about axis 2, I
M4(NP,4) = Moment of Inertia about axis 3, I
M4(NP,5) = Modulus of Elasticity, E
M4(NP,6) = Shear Modulus, G
M4(NP,7) = Mass per unit length of beam

where NP is the specific material property number specified in columns 21 - 25 of the beam card. The local sign convention is given in the following figure.



local beam reference system. Axes 1 and 2 are in the plane defined by plane i, j and k nodes. Axis 1 is defined by line i-j. Axis 3 is perpendicular the i, j, k plane.

LOCAL SIGN CONVENTION



DEFINITION OF POSITIVE BEAM FORCES

+
TRUSS,M1,M2,M3,M4

This operation forms the element stiffness, mass and force-displacement transformation matrices for 3-D truss members. The arrays are stored on low speed storage in sequence and will be used by other structural operations.

M1 is the name of this groups of truss members
M2 is the name of the coordinate array
M3 is the name of the boundary condition array
M4 is an NP by 3 array of section properties in which NP is the number of different section properties and

M4(NP,1) = the cross-section area, A
M4(NP,2) = the Modulus of Elasticity, E
M4(NP,3) = the mass per unit length of the member
This matrix can be loaded by the matrix load operation.

This operation is followed by one card per truss member in (4I5) format with the following information:

Columns	Content
1 - 5	Truss member identification number
6 - 10	Joint number I
11 - 15	Joint number J
16 - 20	Section property number, NP

This operation must be terminated by a blank card.

+ +
LOADI,M1,N1,N2,N3,N4 or LOADI,M1,N1,N2,,N4 or
LOADI,M1,N1,N2,N3 or LOADI,M1,N1,N2

This operation will load an integer array named M1 which has N1 rows and N2 columns. The terms of the array are punched in row-wise sequence on data cards which follow this operation. If N3 is zero or blank, the data must be punched in (16I5) format. If N3 is nonzero, an additional card containing the format of the data cards must follow this operation and preceed the data cards. N4 is optional but note that an extra comma must be used in place of N3 if the user does not supply a format. The matrix M1 will be printed in partitioned form with N4 columns per partition. Lines have (N4 + 1)*5 characters. N4 devaults to 20 causing 125 characters to print per line. The user is cautioned not to overcome the capacity of the printing device in use.

+
PLANE,M1,12,M3,M4,N1,N2

This operation calculates the element stiffness, mass and stress-displacement transformation matrices for 3 to 8 node isoparametric elements. (Y-Z plane only). These arrays are stored in sequence as a group on low speed storage to be used later by other operations (i.e., ADDSF and FORCE). The arguments are defined as

M1 is the user defined name of the element group
M2 is the name of the joint coordinate array
M3 is the name of the boundary condition array
M4 is the name of the array which contains the material properties of the elements (one row per different material) where

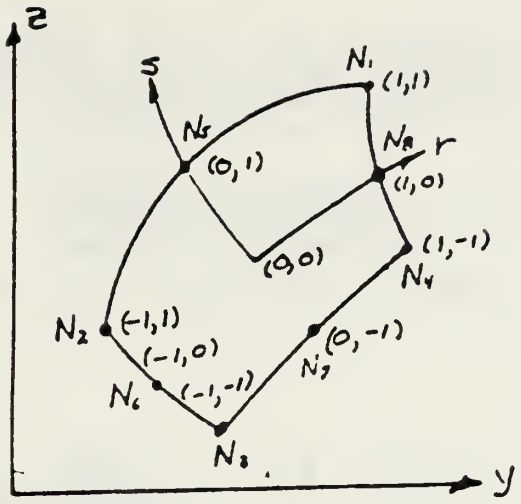
M4(NP,1) = Modulus of Elasticity, E
M4(NP,2) = Poissons Ratio, v
M4(NP,3) = Thickness of the element
M4(NP,4) = Mass density of the element
NP is the material identification number

N1 and N2 are the number of integration points in the r and s directions respectively.

One card for each 3 to 8 node element in the group must follow the operation card. The card is punched in a (10I5,6F5.0) format and contains the following information:

Columns	Contain
1 - 5	element identification number
6 - 10	Node number N1
11 - 15	Node number N2
16 - 20	Node number N3
21 - 25	Node number N4
26 - 30	Node number N5
31 - 35	Node number N6
36 - 40	Node number N7
41 - 45	Node number N8
46 - 50	Material identification number, NP
51 - 55	Natural coordinate of stress output r1
56 - 60	Natural coordinate of stress output s1
61 - 65	Natural coordinate of stress output r2
66 - 70	Natural coordinate of stress output s2
71 - 75	Natural coordinate of stress output r3
76 - 80	Natural coordinate of stress output s3

N4 through N8 are optional. The midside nodes, if present, must be within center half of side. The local numbering system for the element is shown in the following figure.



ISOPARAMETRIC ELEMENT

Stresses will be printed by the FORCE operation at the three points defined in columns 51 through 80. The forces are defined as follows:

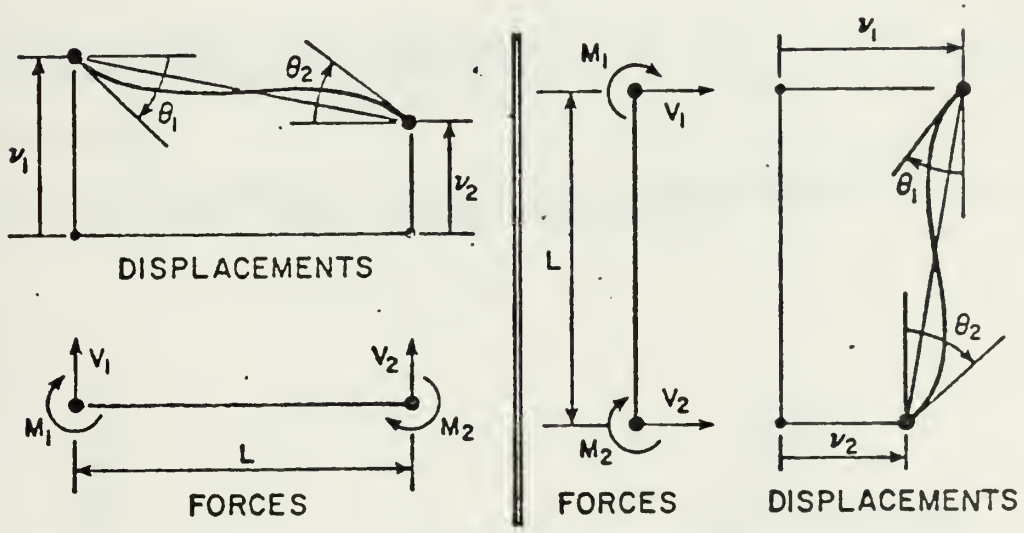
$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \\ F_9 \end{bmatrix} = \begin{bmatrix} \tau_{xx}^{(1)} \\ \tau_{yy}^{(1)} \\ \tau_{xy}^{(2)} \\ \tau_{xx}^{(2)} \\ \tau_{yy}^{(2)} \\ \tau_{xy}^{(3)} \\ \tau_{xx}^{(3)} \\ \tau_{yy}^{(3)} \\ \tau_{xy} \end{bmatrix}$$

SLOPE,M1

This operation forms a 4 x 4 stiffness matrix, M1 for a beam or column member from the classical slope-deflection equations. The properties of the member are defined on one card immediately following the operation. This second card is punched in a (3F10.0) format and contains the following information:

Columns	Contain
1 - 10	Moment of Inertia, I
11 - 20	Modulus of Elasticity, E
21 - 30	Length of Member, L

The sign convention is defined as follows:



The member forces are defined in terms of joint displacements by the following slope deflection equations.

$$M_1 = \frac{EI}{L}\left[4\theta_1 + 2\theta_2 - \frac{6}{L}\left(\nu_1 - \nu_2\right)\right]$$

$$M_2 = \frac{EI}{L}\left[2\theta_1 + 4\theta_2 - \frac{6}{L}\left(\nu_1 - \nu_2\right)\right]$$

$$V_1 = -V_2 = \frac{M_1 + M_2}{L}$$

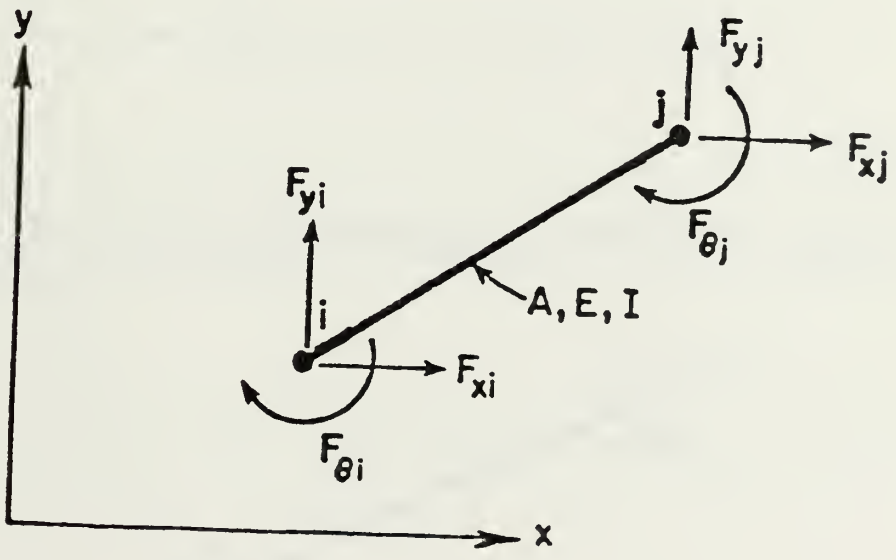
or in matrix form

$$\begin{bmatrix} M_1 \\ M_2 \\ V_1 \\ V_2 \end{bmatrix} = \frac{EI}{L} \begin{vmatrix} 4 & 2 & -\frac{6}{L} & \frac{6}{L} \\ 2 & 4 & -\frac{6}{L} & \frac{6}{L} \\ -\frac{6}{L} & -\frac{6}{L} & \frac{12}{L^2} & -\frac{12}{L^2} \\ \frac{6}{L} & \frac{6}{L} & -\frac{12}{L^2} & \frac{12}{L^2} \end{vmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \nu_1 \\ \nu_2 \end{bmatrix}$$

or symbolically $F = K\Delta$ Where K is the 4 x 4 stiffness matrix defined by the name M1.

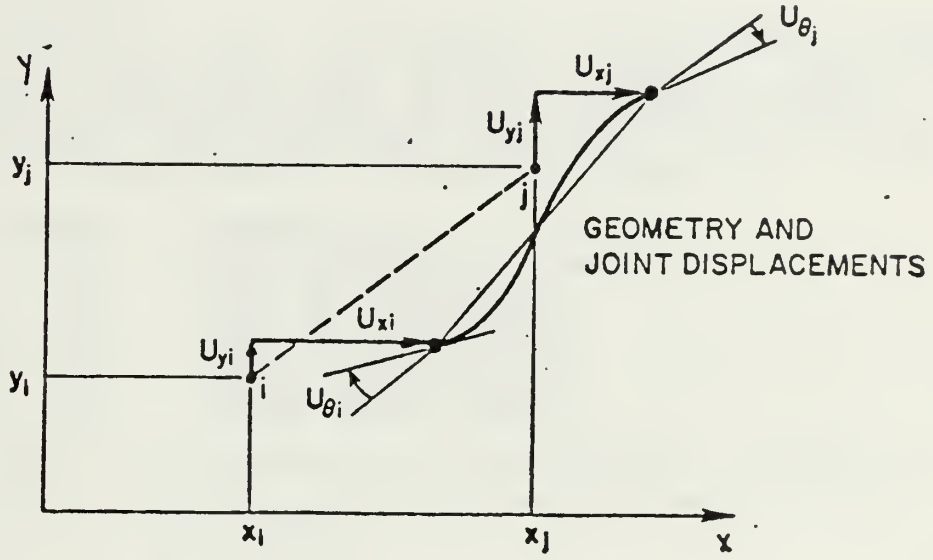
FRAME,M1,M2

This operation forms the 6 x 6 stiffness matrix M1 for the two-dimensional frame member shown below.

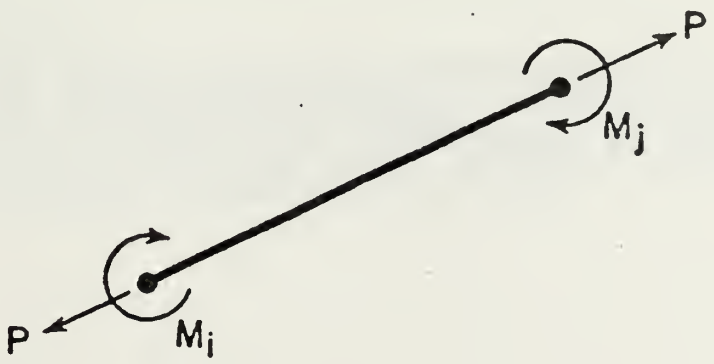


The properties of the member are defined on one card immediately following the FRAME operation card. This second card is punched in a (8F10.0) format and contains the following information:

Columns	Contain
1 - 10	Axial area, A
11 - 20	Modulus of Elasticity, E
21 - 30	Moment of Inertia, I
31 - 40	Xi
41 - 50	Yi
51 - 60	Xj
61 - 70	Yj



M2 is a 3 x 6 force-displacement transformation matrix which is based on the positive difinition of the element forces shown below.



These forces can be calculated from the following matrix equation, with the MEMFRC operation.

$$\begin{bmatrix} M_i \\ M_j \\ P \end{bmatrix} = \underline{M2} \begin{bmatrix} U_{xi} \\ U_{yi} \\ U_{\theta i} \\ U_{xj} \\ U_{yj} \\ U_{\theta j} \end{bmatrix}$$

LOADS,M1,M2,N1

This operation forms a load matrix named M1 of N1 columns (N1 load conditions) where M2 is the name of the boundary condition array generated by the operation BOUND. This operation is followed by a series of cards - one for each loaded joint for each load condition. These cards are punched in (2I5,6F10.0) format as follows:

Columns	Contain
1 - 5	Joint number
6 - 10	Load condition number
11 - 20	Load in X-direction
21 - 30	Load in Y-direction
31 - 40	Load in Z-direction
41 - 50	Moment about X-axis
51 - 60	Moment about Y-axis
61 - 70	Moment about Z-axis

This series of cards must be terminated by a blank card.

ADDSF,M1 or ADDSF,M1,M2

This operation forms the total stiffness matrix named M1 and a lumped mass matrix named M2 for the structural system from the element stiffness and mass matrices which are stored on low speed storage. These matrices can be printed with the PRINT operation. If M2 is not specified, the row mass matrix M2 will not be formed.

ADDK,M1,M2,M3,N1

This operation adds the element stiffness matrix named M2 to the total stiffness matrix named M1, where M1 was previously defined and initially set to zero. M3 is the name of the integer array in which the column number N1 contains the row or column numbers in the total stiffness matrix where the element stiffness terms are to be added.

MEMFRC,M1,M2,M3,+M4,N1

This operation multiplies the element stiffness matrix named M1 by the joint displacement matrix named M2. M3 is the name of the integer array in which the column number N1 contains the row numbers in the displacement matrix, M2, which are to be multiplied by the element stiffness (or force-displacement) matrix, M1. The results of this multplication are stored in the array named M4.

DISPL,M1,M2

This operation prints the displacement named M1 in joint sequence order, where M2 is the name of the boundary condition array.

FORCE,M1,M2,+M3 or FORCE,M1;M2

This operation calculates the member forces for a group of elements in whcih

M1 is the name of the element group
M2 is the displacement matrix
M3 is the name of the matrix in which the forces are stored in the order calculated. If this array is not specified, the element forces will be printed only and will not be retained in storage. For the TRUSS element, only the member axial force, F, will be calculated for each member. For the BEAM element, eight forces will be printed with reference to the positive definiton shown in the BEAM operation.

C. DYNAMIC ANALYSIS OPERATIONS

The following operations were designed to evaluate the dynamic response of structures subjected to arbitrary time-dependent loads. If these operations are used in connection with the standard matrix operations and the sturctural analysis operation, a dynamic analysis is a relatively simple procedure. The user has the option of using the mode superposition method or a direct step-by-step integration of the dynamic equations of motion. The user may examine the spectra of both input loading and calculated displacements. In addition, the contributions of the individual modes may be evaluated and compared.

The most common and convenient form for time-dependent data to be specified is as straight line segments between given time points. Therefore, an operation which generates values at equal intervals is necessary. Another common characteristic of time-varying loads on structures is that it is normally possible to represent the loads at all points on the structure by the product of two matrices, a column matrix indicating the spacial distribution of loads times a row matrix which indicates the values as a function of various times. If a more complicated loading is required, it is possible to perform more analyses, each within the restrictions of the program, and then add the results of each analysis.

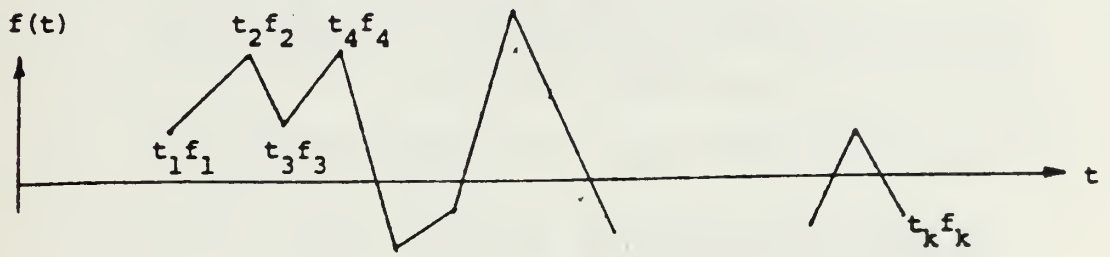
The following operations have been added for the major purpose of performing dynamic analysis.

FUNG,M1,M2,M3,N1,N2

This operation generates a matrix named M2 which contains values at equal intervals of the function specified in the array named M1. The array M1 must be a 2 by k array of the form:

$$M1 = \begin{bmatrix} t_1 & t_2 & t_3 & \cdots\cdots & t_k \\ f_1 & f_2 & f_3 & \cdots\cdots & f_k \end{bmatrix}$$

which numerically represents a function of the form shown below:



The time interval t is specified in the 1 x 1 matrix named M3. N1 specifies the total number of values to be generated, and is the number of columns in M2. If N2 = 0, the array M2 will be a 1 x N1 row matrix in which the first value will be f . If N2 0, the array M2 will be a 2 x N1 matrix of the following form:

$$M2 = \begin{bmatrix} t_1 & t_1 + \Delta t & t + 2\Delta t \ \ldots\ldots\ldots\ldots \\ f_1 & f(t_1+\Delta t) & f(t_1 + 2\Delta t)\ldots\ldots\ldots \end{bmatrix}$$

STEP,M1,M2,M3,M4,M5,M6,M7,M8,N1,N2

This operation calculates the dynamic response of a sturctural system usnig direct step-by-step integration of the following linear matrix equation of motion:

$$\underline{M}\ddot{U} + \underline{C}\dot{U} + \underline{K}U = \underline{R}(t) = \underline{P}\underline{F}(t)$$

Where

M1 is the name of the N x N stiffness matrix K
M2 is the name of the N x N mass matrix M
M3 is the name of the N x N damping matrix C
M4 is the name of the N x 3 initial condition matrix U in which:

U (I,1) is a vector of displacements U
U (I,2) is a vector of velocities $\dot{U}$
U (I,3) is a vector of accelerations $\ddot{U}$

M5 is the name of the N x N2 matrix of calculated displacements in which column "i" represents the displacements at time $i*N1*\Delta t$
M6 is the name of the N x 1 load distribution matrix P
M7 is the name of the 1 x k row matrix representing the load multipliers at equal time increments F, where k = N2/N1
M8 is the name of the 1 x 1 matrix containing Δt
N1 is the output interval for the displacements
N2 is the total number of displacement vectors to be calculated.

The total time for which results will be calculated by this operation is $N1*N2*\Delta t$. This operation must be followed with one data card in (3F10.0) format containing the following information:

Columns	Contain
1 - 10	DELTA
11 - 20	ALPHA
21 - 30	THETA

Different values of delta, alpha and theta will allow the user to select different methods of step-by-step integration. The following table lists some possibliities:

	DELTA	ALPHA	THETA
Newmarks Average Acceleration	1/2	1/4	1.0
Linear Acceleration	1/2	1/6	1.0
Wilson's Theta Method (low damping)	1/2	1/6	1.42
Wilson's Theta Method (high damping)	1/2	1/6	2.0

EIGEN,M1,M2,M3,N1

This operation solves the following eigenvalue problem:

$$K\phi = M\phi\lambda$$

In which the N x N, symmetric, positive-semidefinite matrix K is named M1. The matrix M is a diagonal matrix of nonzero, positive terms designated by M3. The matrix M3 must be a row or column matrix containing only the diagonal terms of M. The eigenvalues, λ, are stored in matrix M3. The eigenvalues are ordered in numerically increasing order and the eigenvectors, ϕ, are stored in the corresponding columns of the matrix M2. The number N1 specifies the approximate number of significant figures of the eigenvalues. If N1 is zero or blank, 4 figure accuracy will be used. The maximum accuracy possible is 16 figures. The use of more than 12 figure accuracy is not recommended.

The program reduces the problem to standard eigenvalue form by the following transformation

where

$$K^* = m^t K m$$

$$I = m^t M m$$

in which

$$m_i = 1/\sqrt{M_{ii}}$$

The calculated mode shapes, ϕ, are normalized as follows:

$$\phi^t M \phi = I \qquad \phi^t K \phi \quad \lambda$$

The program uses the standard Jacobi diagonalization method to solve for all eigen values and eigenvectors.

DYNAM,M1,M2,M3,M4,M5,M6,N1

This operation evaluates the following set of uncouples second order differential equations associated with the mode superposition method for the dynamic analysis of a structural system.

$$\ddot{X}_i + 2\lambda_i \omega_i \dot{X}_i + \omega_i^2 X_i = P_i(t) \qquad i = 1 \text{ to } N \text{ nodes}$$

M1 is the name of a row or column matrix which contains the N terms (frequencies in rad/sec). M2 is the name of a row or column matrix which contain the N λ_i terms (ratio of modal damping to critical damping).

The generalized time-varying forces P_i (t) are not specified directly but are evaluated from more fundamental information. The forces for all modes are evaluated at specific times by the program from the following matrix equation:

$$P = p*f = M3*M4$$

In which p is a specified N x 1 vector named M3, and f is a 1 x N1 row matrix which will be generated from the 2 by k array named M4. The array M4 is the same form as the input array described under the operation FUNG. It is not necessary to use FUNG before the DYNAM operation.

M5 is the name of the N x N1 array which contain the generalized displacement X_i (t).

M6 is the name of the 1 x 1 array which contains the time increment associated with the generalized displacements.

N1 is the number of displacements to be generated.

The method of integration used is exact for straight line secments.

PLOT,M1,N1

This operation will prepare a printer plot of selective rows of the matrix named M1. N1 is the number of rows of M1 which will be plotted by this operation. This operation is followed by N1 cards in (1A1,I4) format with the following information:

Columns	Contain
1	Plot symbol - any keypunch symbol
2 - 5	Row number to be ploted

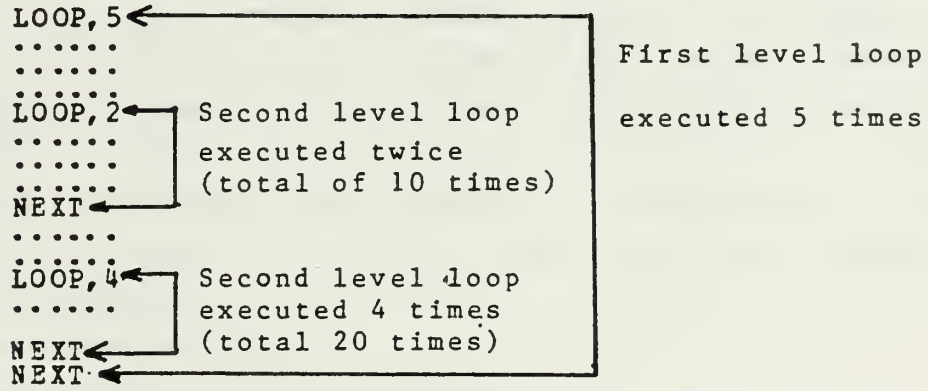
The program automatically searches the information to be plotted for the maximum and minimum values. The difference in these numbers divided by 120 spaces is selected as the plot scale.

D. LOOPING OPERATIONS

CAL has a five level looping ability. The first operation is LOOP and the last operation is NEXT. Operations withing CAL are normally executed as they are encountered. If the operation requires data, the data cards follow the operation card. In the case of looping, however, all operation cards from the first LOOP card to the last NEXT card are stored within the computer before they are executed; therefore, if operations within the loops requre data, the data cards must be supplied in the order required after the last NEXT operation. If an error is encountered while executing in a loop, the entire matrix of loop commands is deleted and the user is given the opportunity to try again. Matrices that have been modified by operations successfully completed while in the loop remain modified. After all loops are executed the computer storage required for these operations is automatically released by the program. The looping operations are:

LOOP,N1

N1 is the number of times the loop is to be executed. Associated with each LOOP operation there must be a corresponding NEXT operation which signifies the end of the Loop and the return of the control to the beginning of the loop. The following is a possible series of looping operations.



data for all operations within all loops

NEXT,M1 or NEXT

The operation NEXT signifies the end of a loop. It is apparent which LOOP and NEXT cards are associated if there are an equal number of each. The operation NEXT,M1 will cause the loop to terminate if the first term in the matrix named M1 is negative.

SKIP,M1,N1

This operation will cause the skip of the next N1 operations if the first term in the matrix named M1 is negative. This level of looping.

E. USER DEFINED OPERATIONS

USERA and USERB

These names are reserved for operations to be defined and programmed by the user. In order to program these operations is is necessary to understand the internal organization of CAL. Chapter III contains details.

V. LARGE PROBLEMS

CAL is designed as an educational tool. It does not take advantage of banding and symmetry in matrix storage. Larger problems can be solved by increasing the dimension of the L array but a general purpose program that makes maximum advantage of out-of-core storage and takes advantage of banding and symmetry for in-core matrix storage is probably a better choice. With the above disclaimer, to increase problem size capability, increase the dimension of the L array and change the value of MAX to the new dimension size in the following:

```
C-----MAIN PROGRAM
C-----SET PROGRAM CAPACITY
      COMMON NTOT,NDP,L(6000)
      MTOT=6000
      NDP=2
      CALL SETIME
      CALL CAL1
      STOP
      END
```

SETIME is an OS routine to initialize the CPU timer and should not be used for CP/CMS programs. With the dimension of the L array as above, the program currently executes in 144k bytes for OS and 256k bytes for CP/CMS. The region necessary for execution will increase about eight times the increase in the L array.

LIST OF REFERENCES

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3. University of California Report No. UC SESM 77-2, CAL Computer Analysis Language for the Static and Dynamic Analysis of Structural Systems, by E. L. Wilson, January 1977.

4. Day, A.C., Fortran Techniques, Cambridge University Press, 1972.

5. Kreitzberg, C.B. and Shneiderman, B., The Elements of Fortran Style: Techniques for Effective Programing, Harcourt Blace Jovanovich, Inc., 1972.

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